The China-Brazil Program of Space Debris Monitoring

(and the monitoring of navigation satellites)

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ABSTRACT

The number of Earth's orbiting artificial bodies larger than 2cm across ranges 500,000, whereas only those larger than 10cm are catalogued. This highlights the need for new approaches for their detection on substantially larger numbers and enabling quick ephemeris evaluation.

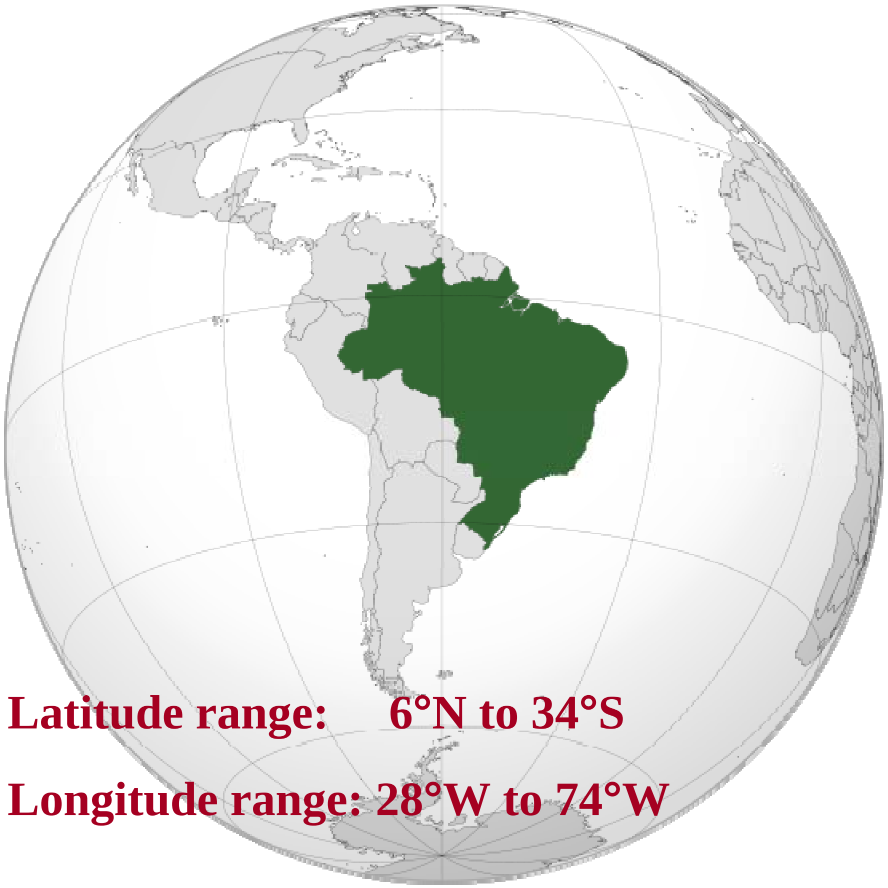
As an increasing number of countries actually use their allotted slots to launch commercial and science satellites, so grows the rate of graze encounters and evasion maneuvers. Additionally new detection methods can be used on astrometric observations of asteroids, near earth objects, and even astronomical observatories for correction to their instantaneous position and speed. Finally the cloud of debris itself can be used on dynamics studies of the geopotential and orbit propagation methods.

Taking advantage of their large and geographically complementary territories, the China-Brazil Program of Space Debris Monitoring meets their satellite areas demands by an astrometry and dynamics driven expertise consortium. A distinct feature is the use of short focus telescopes, and drift scanning and rotating CCDs. A chief example of the collaboration is from the São Paulo MEADE 40cm telescope jointly installed and remotely operated.

We present an account of the program, instruments, methods, and rst results.

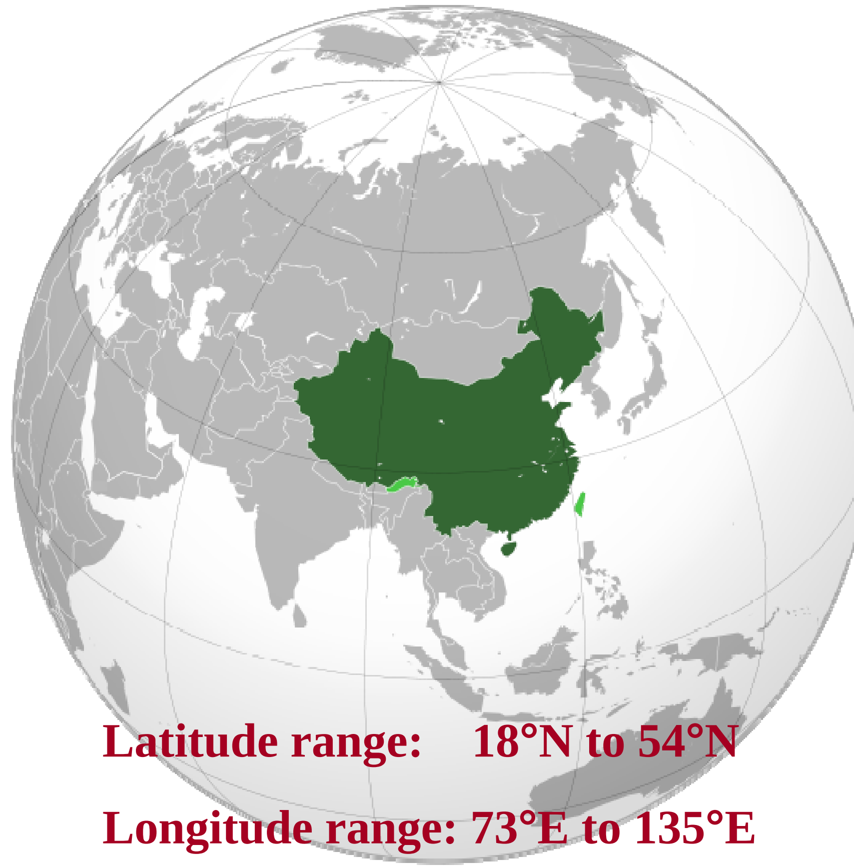
(We end by presenting the essentials of the project for common tracking of the Compass navigation satellites cloud.)

• Complementary geographical location



Latitude range: 6°N to 34°S

Longitude range: 28°W to 74°W



Latitude range: 18°N to 54°N

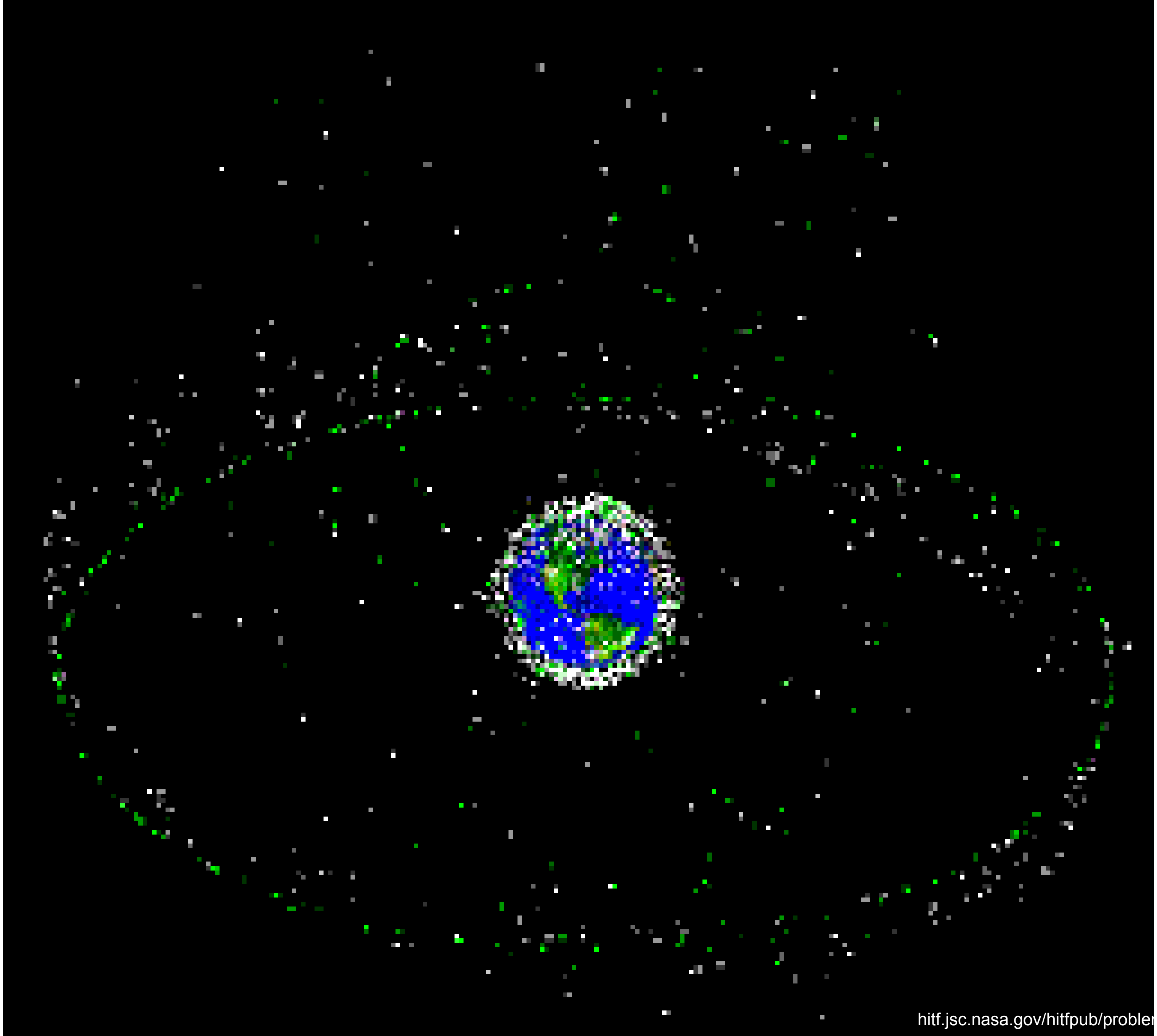
Longitude range: 73°E to 135°E

• **Strong astrometric and geophysics communities**

- About 6000 satellites launched to date
- 800 presently operational
- 400 in the LEO[(1)] and GEO[(2)] orbits

[(1)] LEO altitude between 200km and 2,000km

[(2)] GEO altitude at 35,000km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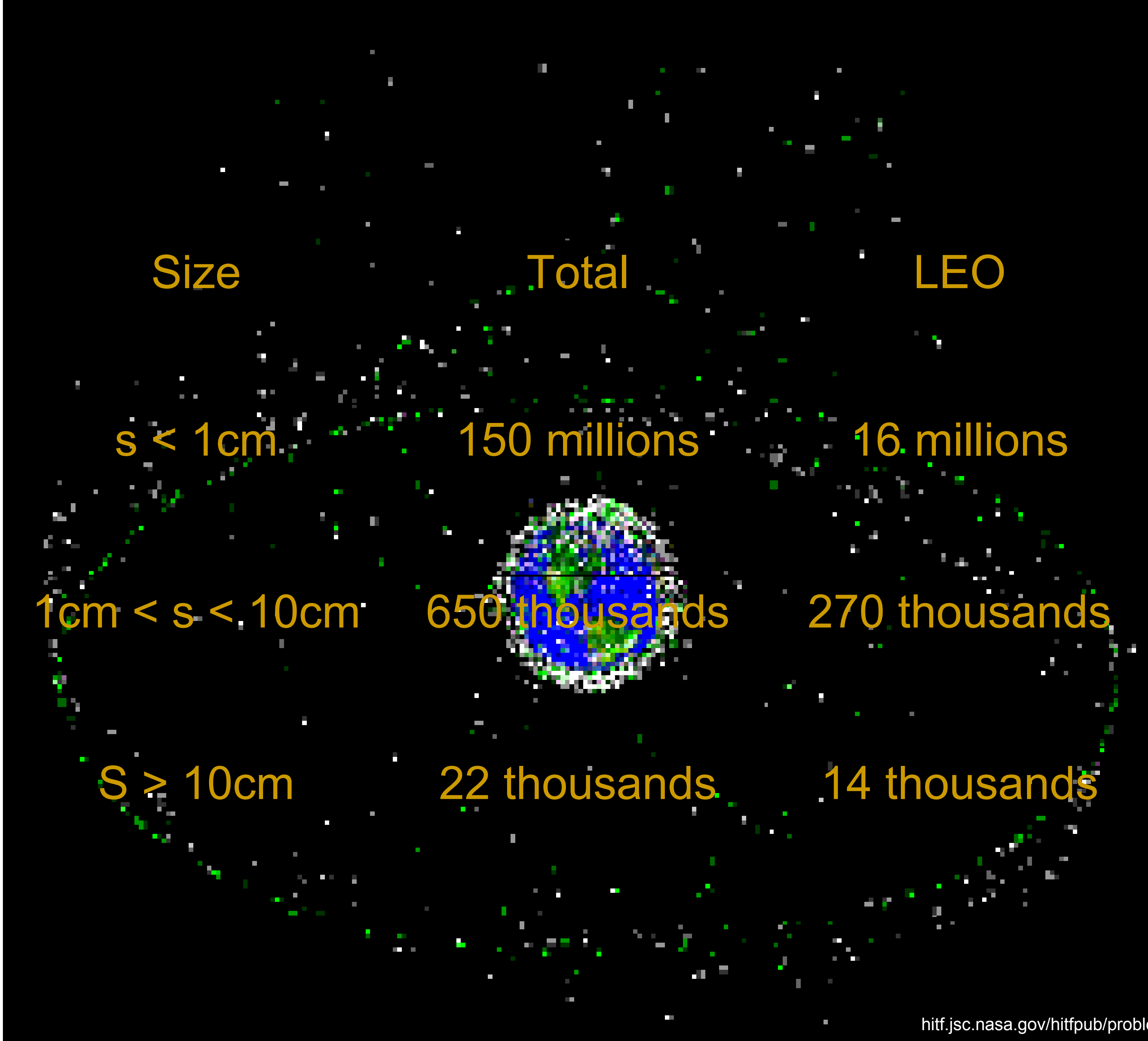

Size	Total	LEO
s < 1cm	150 millions	16 millions
1cm < s < 10cm	650 thousands	270 thousands
S > 10cm	22 thousands	14 thousands

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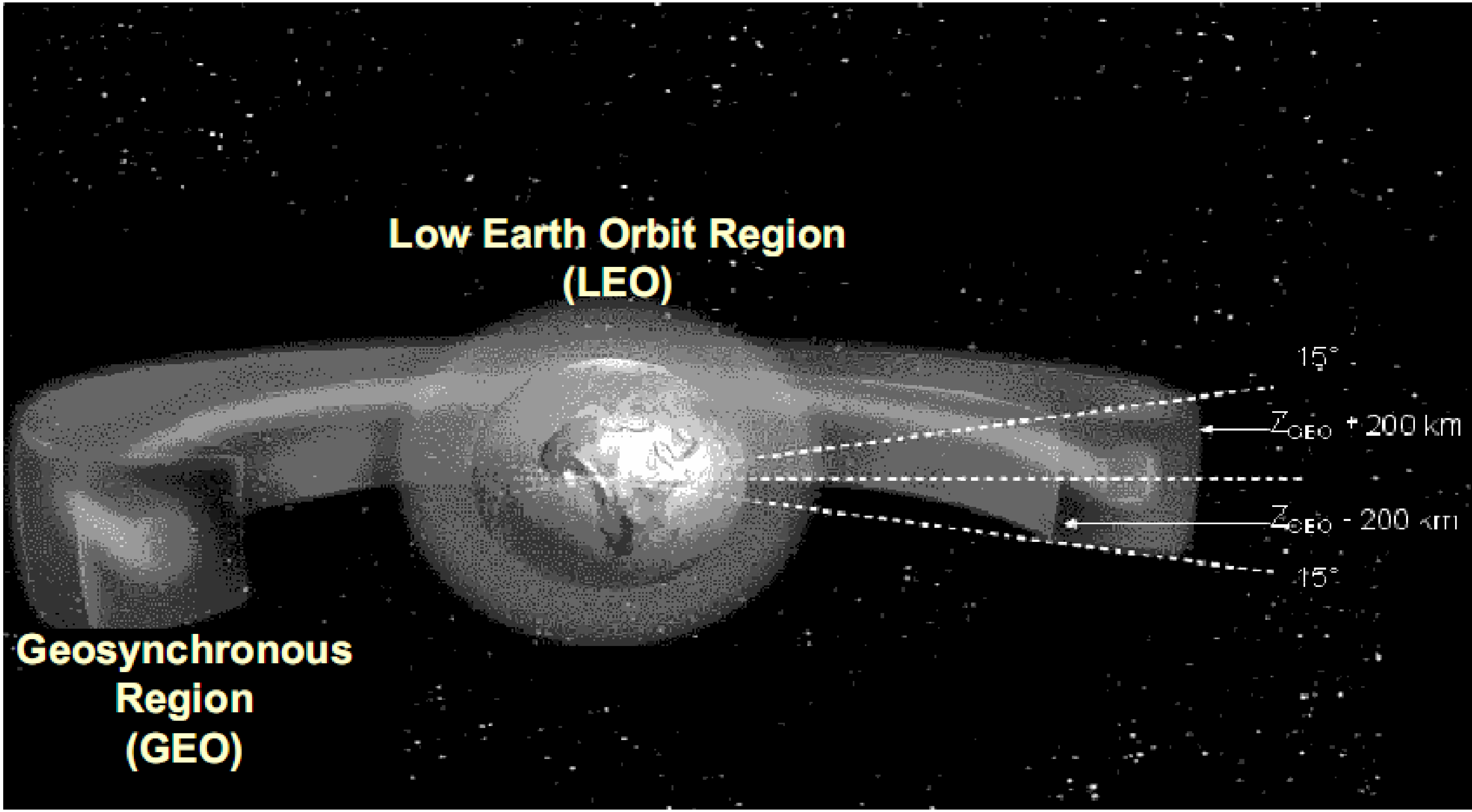
Orbits protected regions



- Space debris decay. Below 300km high orbit decay time is of few months. Around 600km the decay time is of few years. Around 800km of few decades. And around 1000km of few centuries.
- Small debris are more affected by atmospheric or solar wind drag and decay more rapidly. Hence high solar activity hastens up the decay.
- The United Nations since 1959 legislates on the Exploration and Use of Cosmic Space, on Objects Launched into Cosmic Space, Artificial Satellites, Broadcast, Science, and Geodesy Satellites, and on defining the concept of “Launch-capable State”.
- Guidelines have been discussed for space debris mitigation. They contemplate limiting the rejects during the normal operation of space systems, minimizing the risk of abnormal annihilation, minimizing risks of collision, minimizing risks of end-of-mission explosion, limiting the end-of-mission parking at the LEO or GEO regions.
- Guidelines have been discussed to establish a graveyard orbit at least 200km above GEO.

Decay rate and the Solar Cycle

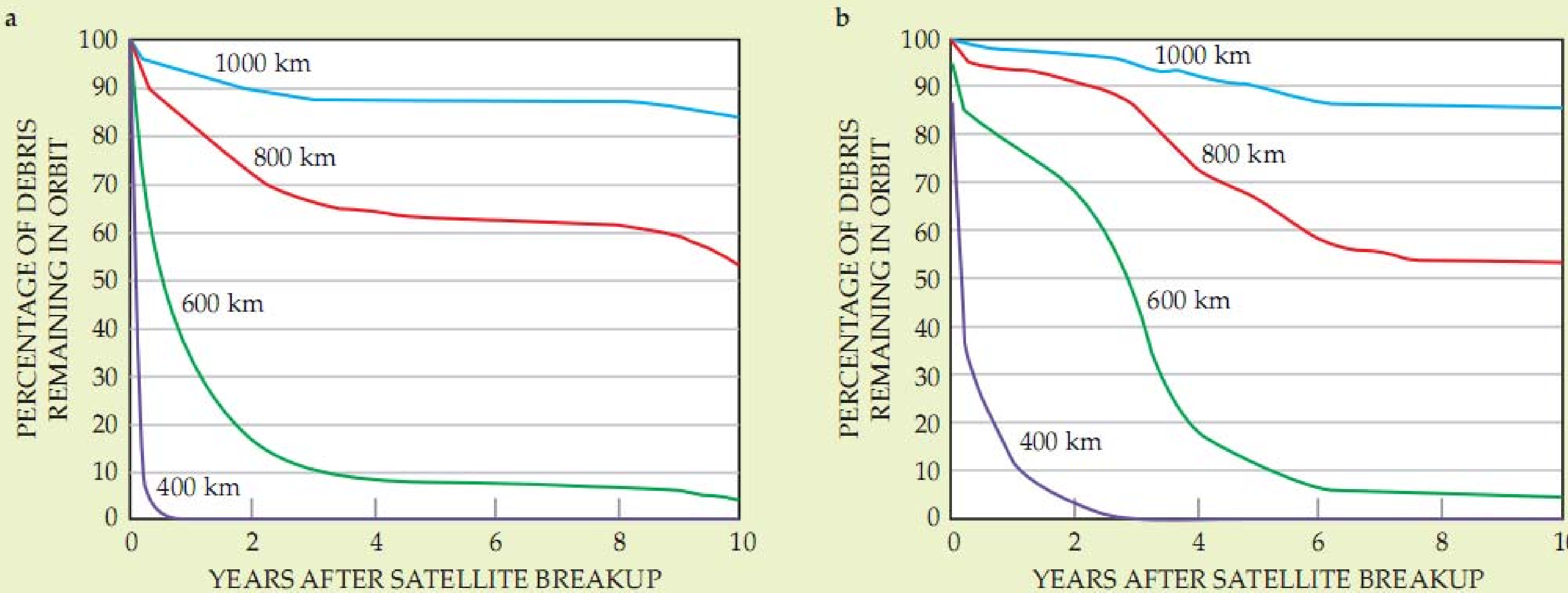


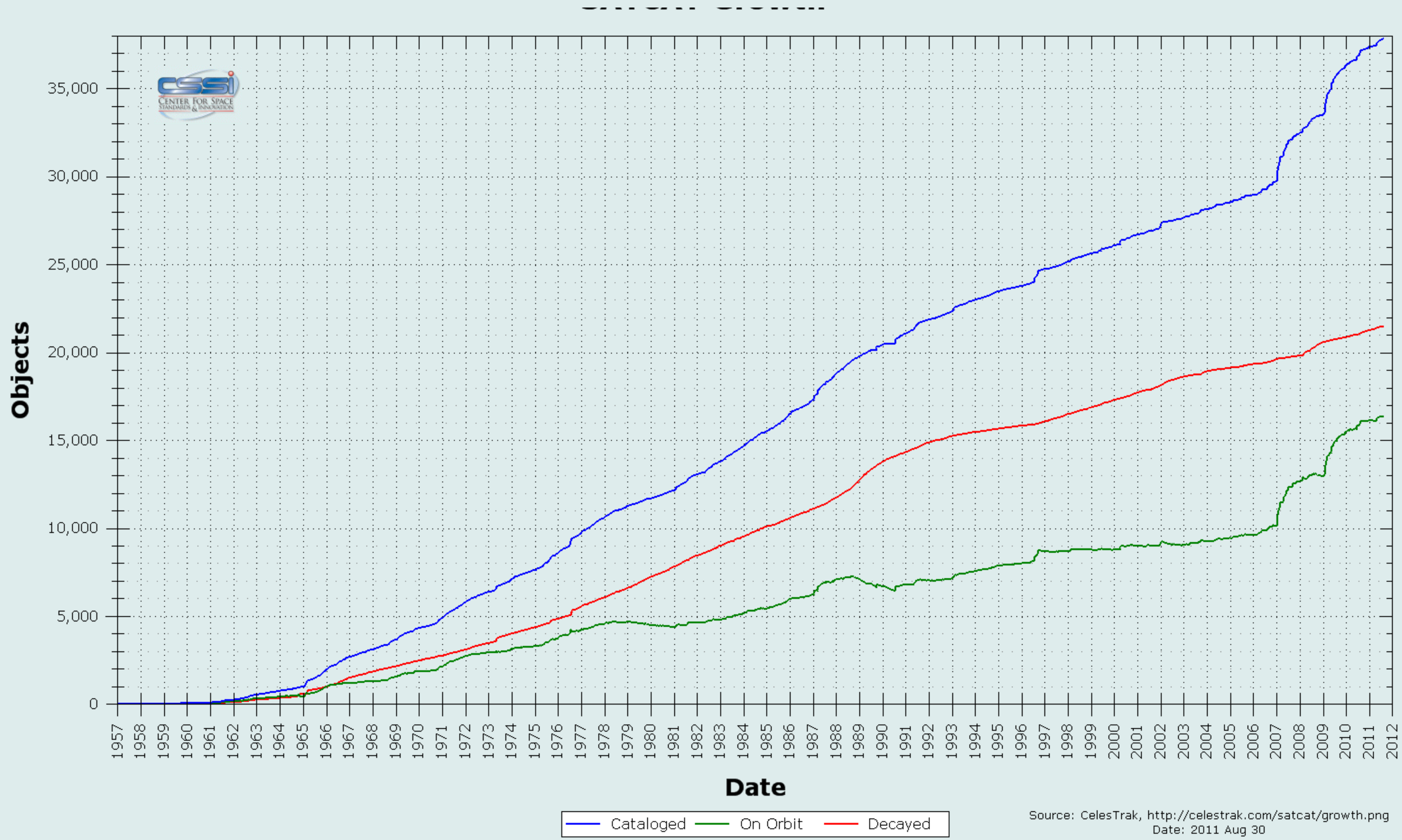
Figure 5. Effect of the 11-year solar cycle on the fraction of debris particles greater than 10 cm that remain in orbit following the catastrophic breakup of a satellite. The results are shown for a satellite in a circular orbit at four different altitudes, with the debris population given by the NASA breakup model. Calculations were made using atmosphere models that reflect the conditions **(a)** at a time of maximum solar activity (1 January 1980) and **(b)** at a time of minimum solar activity (1 January 1986).

Fonte: Physics Today, 2007

- Keller syndrome predicts that in the past sources produce debris at a rate that *was proportional to the number of objects in orbit*, while the future frequency of collisions will produce debris at a rate that *is proportional to the* *square* *of the number of objects in orbit.*
- Increasing number of Launch-capable States. 73 countries presently, and another 23 other about to launch the first satellite.
- Ever increasing number of type of payloads: scientific, broadcast, weather, navigation, commercial, geophysics, weaponry and spy, military, etc.

SATCAT Boxscore

Current as of 2011 August 30



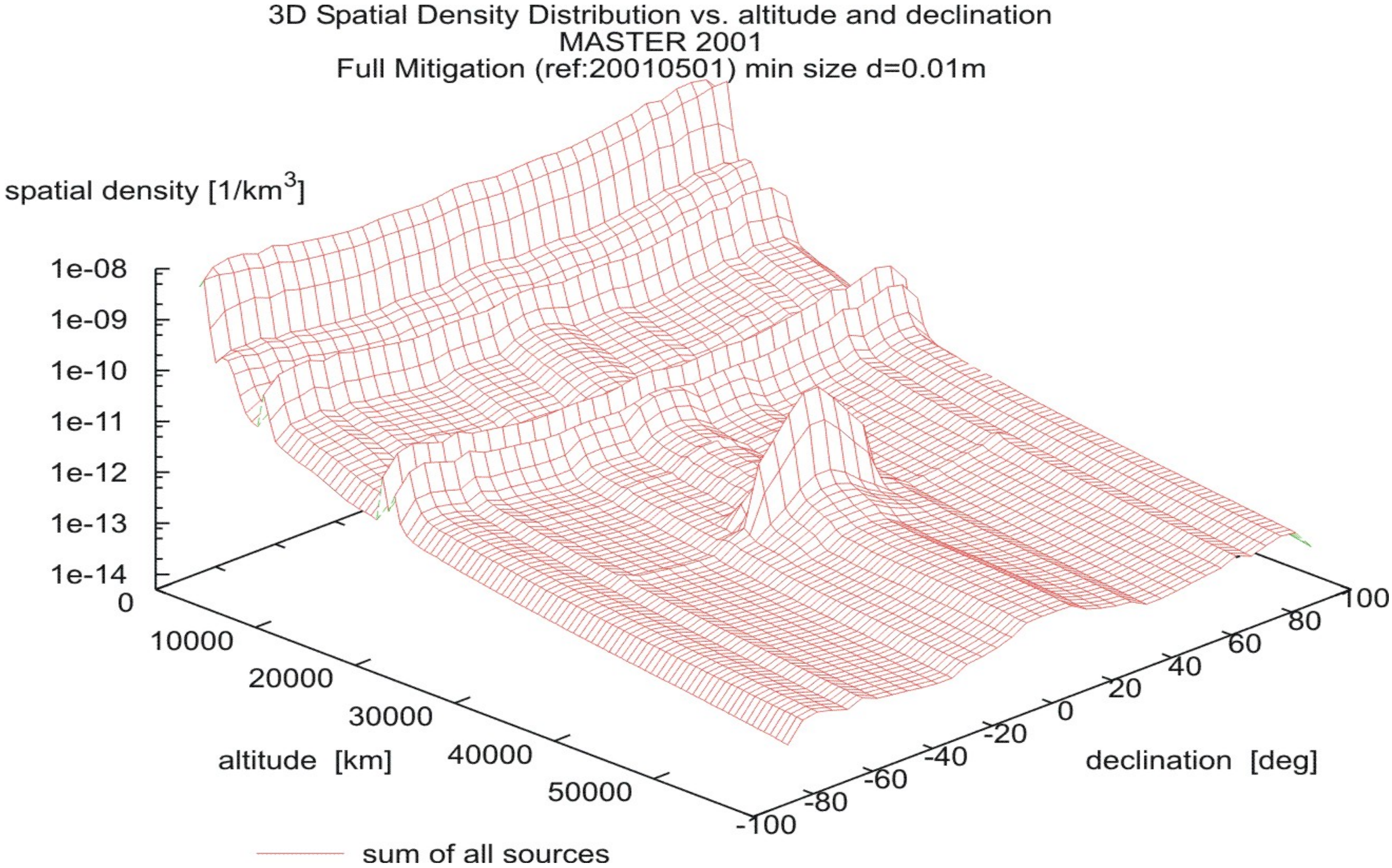
Source	Payloads				Debris			All		
	On Orbit	Decayed	Total	Active	On Orbit	Decayed	Total	On Orbit	Decayed	Total
All	3,539	2,860	6,399	1,070	12,790	18,607	31,397	16,329	21,467	37,796

- The service SOCRATES - Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space, from the Center for Space Standards & Innovation (CSSI – a private company) provides regular information on pending conjunctions on orbit over the coming week. The service aims to help satellite operators to avoid undesired close approaches through advanced mission planning.
- The NORAD – North American Aerospace Defense Command (a military USA/Canada agency) keeps the NORAD Space Catalogue aim to provide update ephemeris for all orbiting objects larger than 1cm.
- This work has actually now taken over by USSPACECOM – United States Space Command.
- But a searchable catalogue can be found at the NASA-NOAA n2yo database site.
- **The China-Brazil program was developed to answer the needs of their satellite programs and to complement the information available in the public databases, using a different tracking method.**

Astrometric and Photometric Solution

- Damaging impact can come from space debris at different orbits, both on height and inclination; at different speed, both in modulus and direction; of different sizes, shapes, and material. Either catalogued or not, and either with updated ephemeris or not.
- Therefore a common astronomical sky patrol would be efficiency wanting. And a sophisticated (i.e., large telescopes, large fields of view) would be cost prohibited.
- A third way turns the very debris movement into an observational advantage, which enables: finding, enhancing, and follow the debris.

- **Based on early CCD tracking methods, the technique was developed at the Shanghai Observatory. It is termed Rotating drift-scan, RDS.**



Ref: Schildknecht, 2005

Apparent magnitude of a 30cm*30cm object

angle / Orbit altitude	0	15	30	45	60	75	90	105	120	135	150	165
200km	7.3	7.4	7.5	7.6	7.9	8.2	8.6	9.1	9.7	10.6	11.9	14.1
300km	8.2	8.2	8.3	8.5	8.7	9.0	9.4	10.0	10.6	11.5	12.8	15.0
400km	8.8	8.9	9.0	9.1	9.4	9.7	10.1	10.6	11.2	12.1	13.4	15.6
500km	9.3	9.3	9.4	9.6	9.8	10.2	10.6	11.1	11.7	12.6	13.9	16.1
600km	9.7	9.7	9.8	10.0	10.2	10.6	10.9	11.5	12.1	13.0	14.3	16.5
800km	10.3	10.4	10.5	10.6	10.9	11.2	11.6	12.1	12.7	13.6	14.9	17.1
1000km	10.8	10.9	11.0	11.1	11.4	11.7	12.1	12.6	13.2	14.1	15.4	17.6
1200km	11.2	11.2	11.3	11.5	11.7	12.1	12.5	13.0	13.6	14.5	15.8	18.0
1500km	11.7	11.7	11.8	12.0	12.2	12.5	12.9	13.4	14.1	15.0	16.3	18.5

Sky:20mag, Seeing:2",Albedo=0.5, SNR>3

Apparent magnitude of a 10cm*10cm object

angle / Orbit(km)	0	15	30	45	60	75	90	105	120	135	150	165
200	9.7	9.7	9.8	10.0	10.2	10.6	10.8	11.5	12.1	13.0	14.3	16.5
300	10.6	10.6	10.7	10.9	11.1	11.4	11.8	12.3	13.0	13.9	15.2	17.4
400	11.2	11.2	11.3	11.5	11.7	12.1	12.5	13.0	13.6	14.5	15.8	18.0
500	11.7	11.7	11.8	12.0	12.2	12.5	12.9	13.4	14.1	15.0	16.3	18.5
600	12.1	12.1	12.2	12.4	12.6	12.9	13.3	13.8	14.5	15.4	16.7	18.9
800	12.7	12.8	12.9	13.0	13.3	13.6	14.0	14.5	15.1	16.0	17.3	19.5
1000	13.2	13.2	13.3	13.5	13.7	14.0	14.4	15.0	15.6	16.5	17.8	20.0
1200	13.6	13.6	13.7	13.9	14.1	14.4	14.8	15.3	16.0	16.9	18.2	20.4
1500	14.1	14.1	14.2	14.4	14.6	14.9	15.3	15.8	16.5	17.4	18.7	20.9

Sky:20mag, Seeing:2",Albedo=0.5, SNR>3

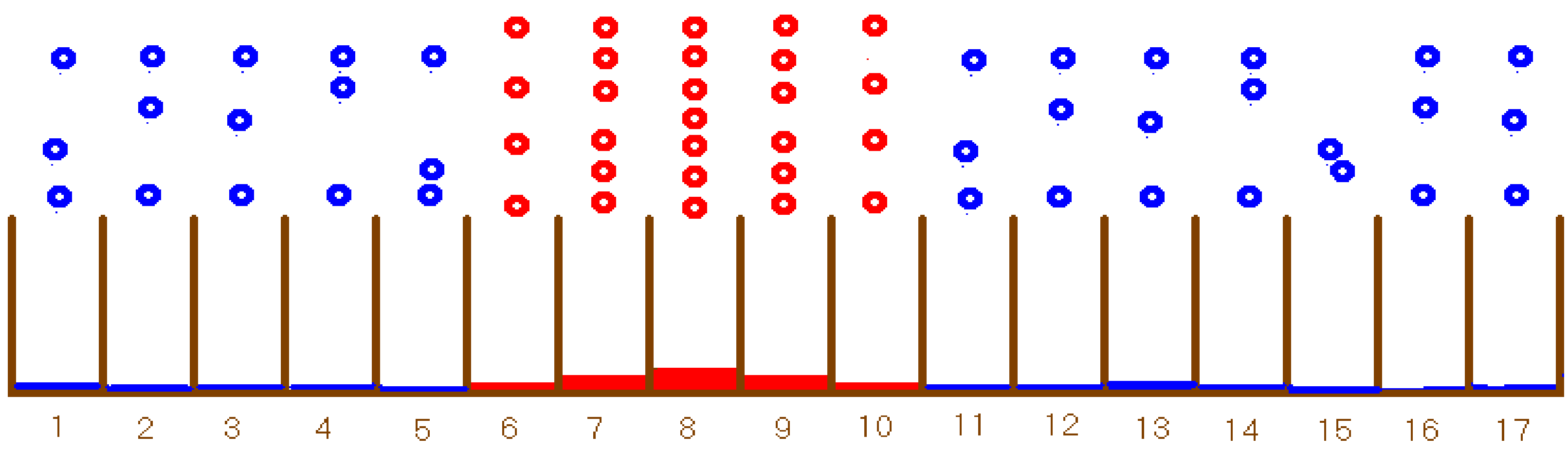
Apparent magnitude of a 2cm*2cm object

angle / orbit(km)	0	15	30	45	60	75	90	105	120	135	150	165
200	13.2	13.2	13.3	13.5	13.7	14.0	14.4	15.0	15.6	16.5	17.8	20.0
300	14.1	14.1	14.2	14.4	14.6	14.9	15.3	15.8	16.5	17.4	18.7	20.9
400	14.7	14.7	14.8	15.0	15.2	15.6	15.9	16.5	17.1	18.0	19.3	21.5
500	15.2	15.2	15.3	15.5	15.7	16.0	16.4	16.9	17.6	18.5	19.8	22.0
600	15.6	15.6	15.7	15.9	16.1	16.4	16.8	17.3	18.0	18.9	20.2	22.4
800	16.2	16.2	16.3	16.5	16.7	17.1	17.5	18.0	18.6	19.5	20.8	23.0
1000	16.7	16.7	16.8	17.0	17.2	17.5	17.9	18.4	19.1	20.0	21.3	23.5
1200	17.1	17.1	17.2	17.4	17.6	17.9	18.3	18.8	19.5	20.4	21.7	23.9
1500	17.6	17.6	17.7	17.9	18.1	18.4	18.8	19.3	20.0	20.9	22.1	24.4

Sky:20mag, Seeing:2”,Albedo=0.5, SNR>3

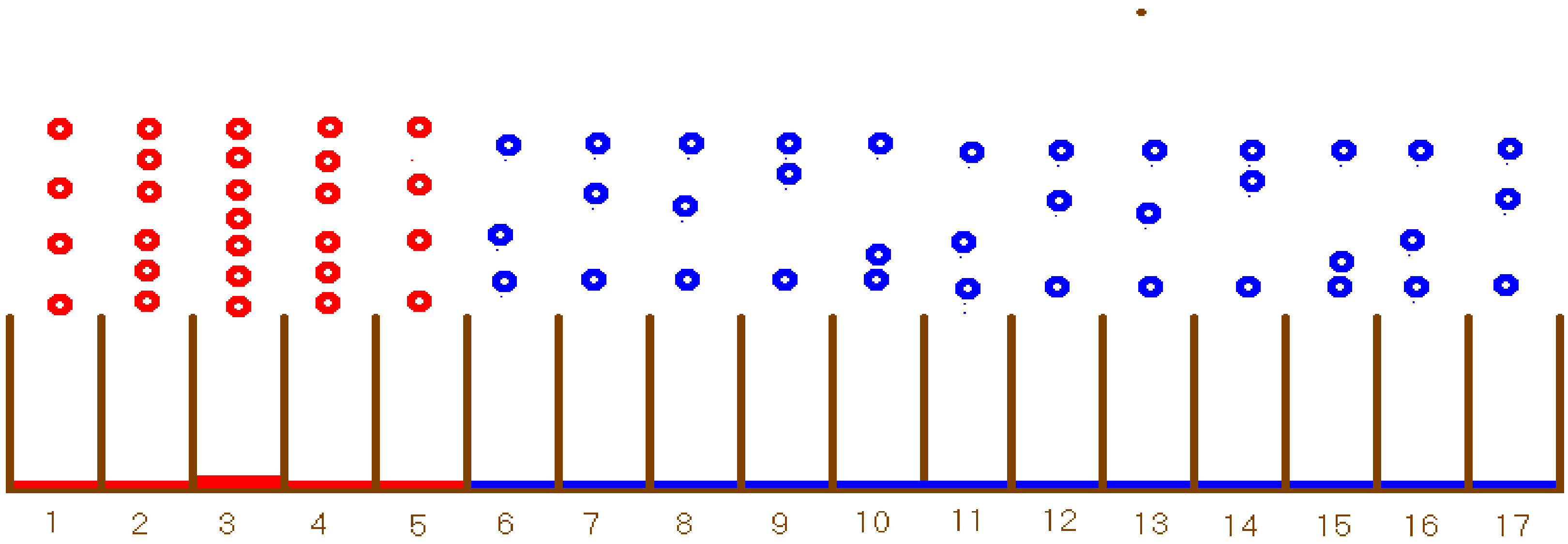
Exposure in Stare mode (normal)

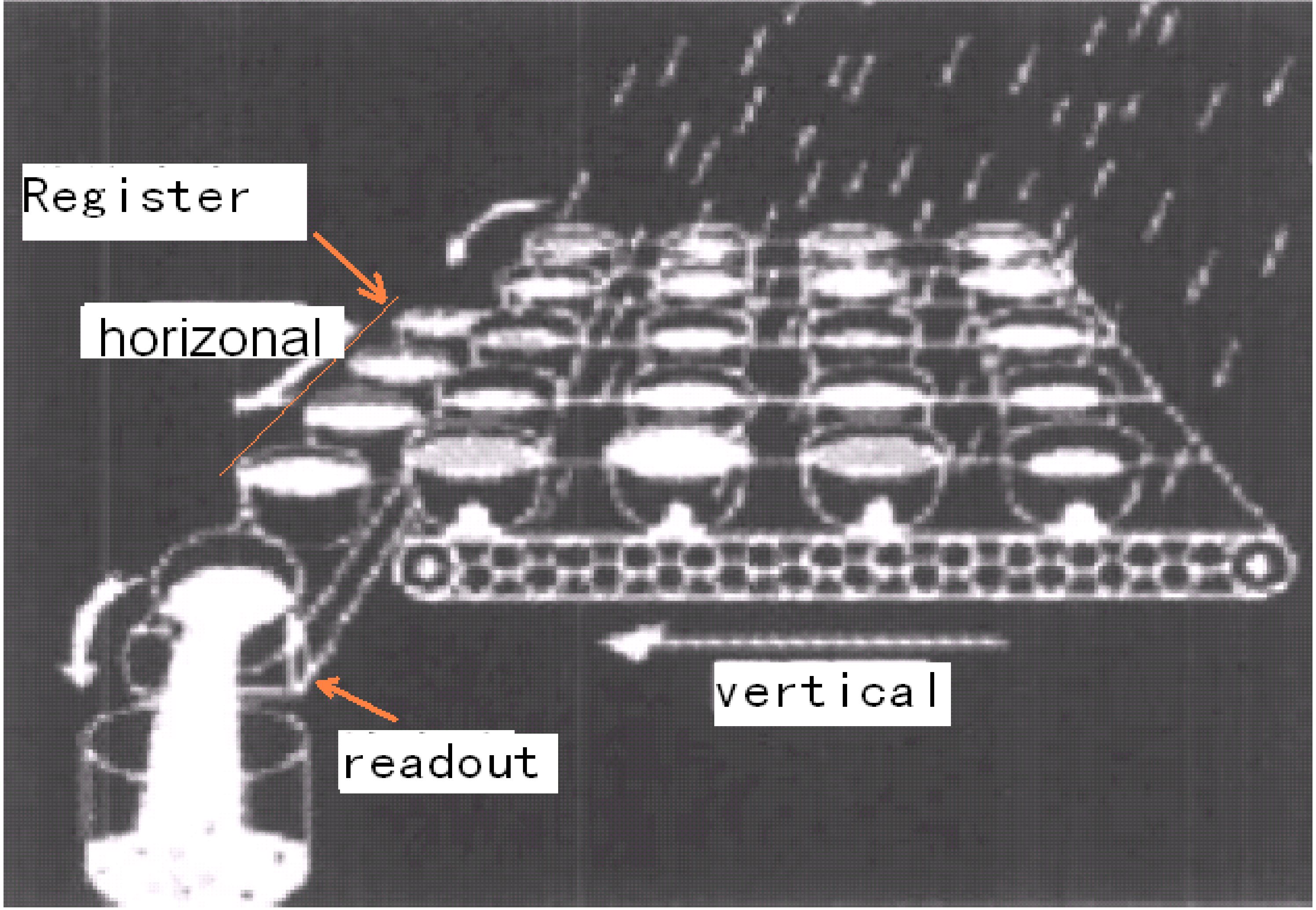
- The telescope tracks the stars.
- The image of one star covers some fixed pixels.



Exposure in Drift-scan mode

- Telescope does not track the stars,
- The image of any given star moves on the CCD, and charges are transported along with matching speed.





Principle of CCD: Photoelectric effect: photons → charges

The program long term strategy in a nutshell

- Start concentrating on GEO objects, objects that might pose a threat to the Compass cloud, and objects of particular interest of each team.
- Next, target objects with known or suspected poor ephemeris.
- The aim is to build a net of robotic telescopes of large FOV (field of view) capable of observing in stare mode to detect debris, and to switch to RDS mode on receiving an alert in order to establish good astrometry and an arc of orbit combining the astrometry of a number of telescopes.
- Establish this communicating robotic telescopes network across the China and Brazil territories.
- Partnership of methods, observations, and database.

The RDS - Rotating-drift-scan CCD technique in a nutshell

- Drift-scan mode, also called TDI for time-delay integration, have been used since 1980s to observe stars, in special for meridian observations or in surveys.
- In 2006, the idea of Rotating-drift-scan CCD was presented as a possible solution for observing faint space debris in low orbit.

- **And, for each target:**

(1) Point the telescope to the direction in which the object will appear. Rotate the CCD to make the charge movement direction parallel to movement of the object.

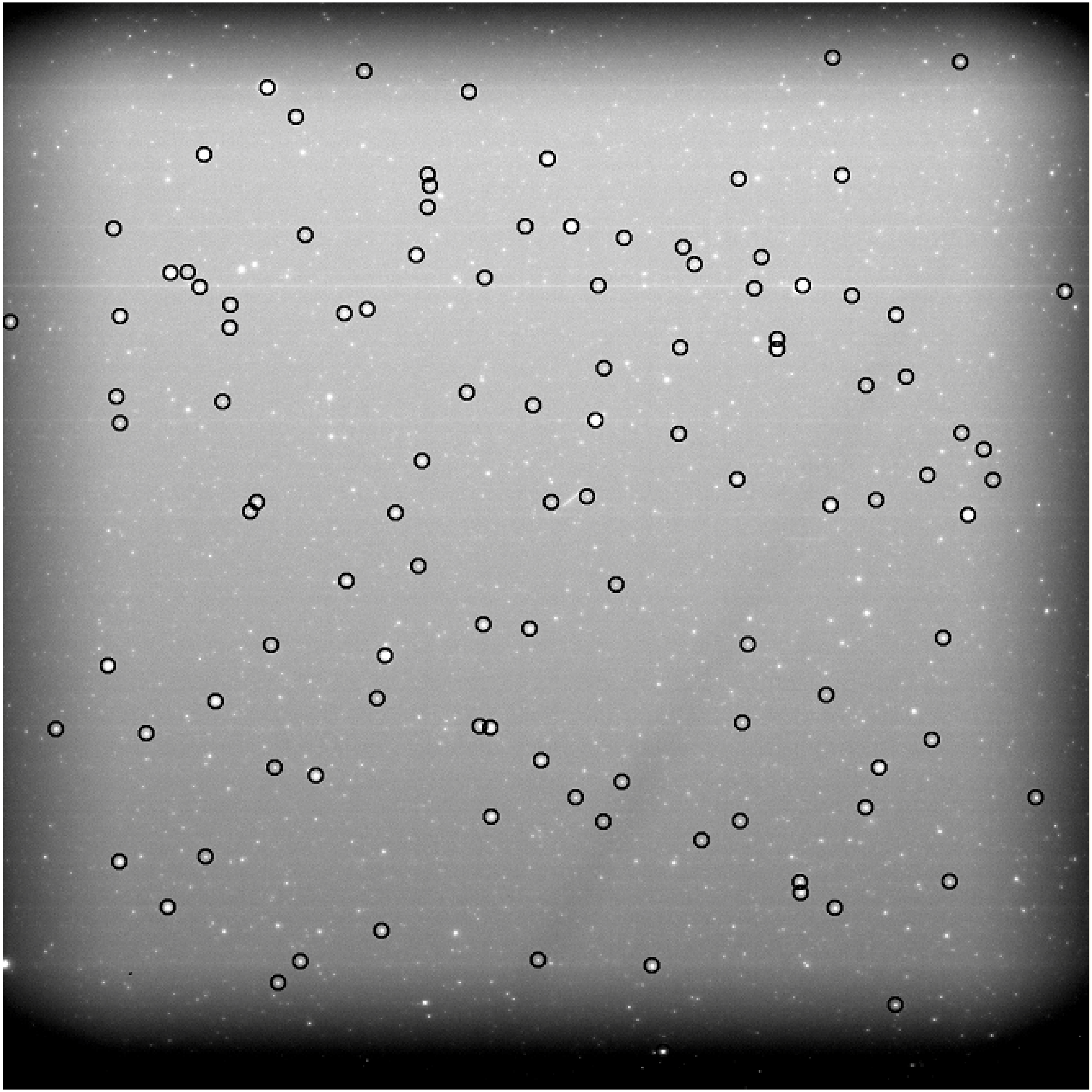
(2) Before the object enters the FOV, expose a short time in stare mode (typically 1s), to build the stellar local frame.

(3) Perform drift-scan mode exposures continuously till the object leaves the FOV.

(4) Expose a short time in stare mode again – to improve on the establishment of the stellar local frame.

Procedure of data reduction

- Detect stars from stare mode frames.
- Match stars with reference catalog.
- Build a transformation function from measured (X,Y) coordinates to local frame (α,δ) equatorial coordinates.
- As the FOV is large, the many reference stars allow the modeling of a polynomial function correcting for field distortion.
- Build a time dependent transformation function from measured CCD count to catalogue magnitude, again the large field allows to model instantaneous field sensitivity (on top of flat field map)
- Detect object from drift-scan mode frames
- Calculate positions and magnitude of objects, through the transformation functions
- Since the telescope keeps stable during one round of observation, each pixel of CCD corresponds to fixed equatorial coordinates. The positions and magnitudes of the objects can thus be calculated with the help of the reference of stars.



Advantages of the RDS technique

(1) No need of precise orbit prediction

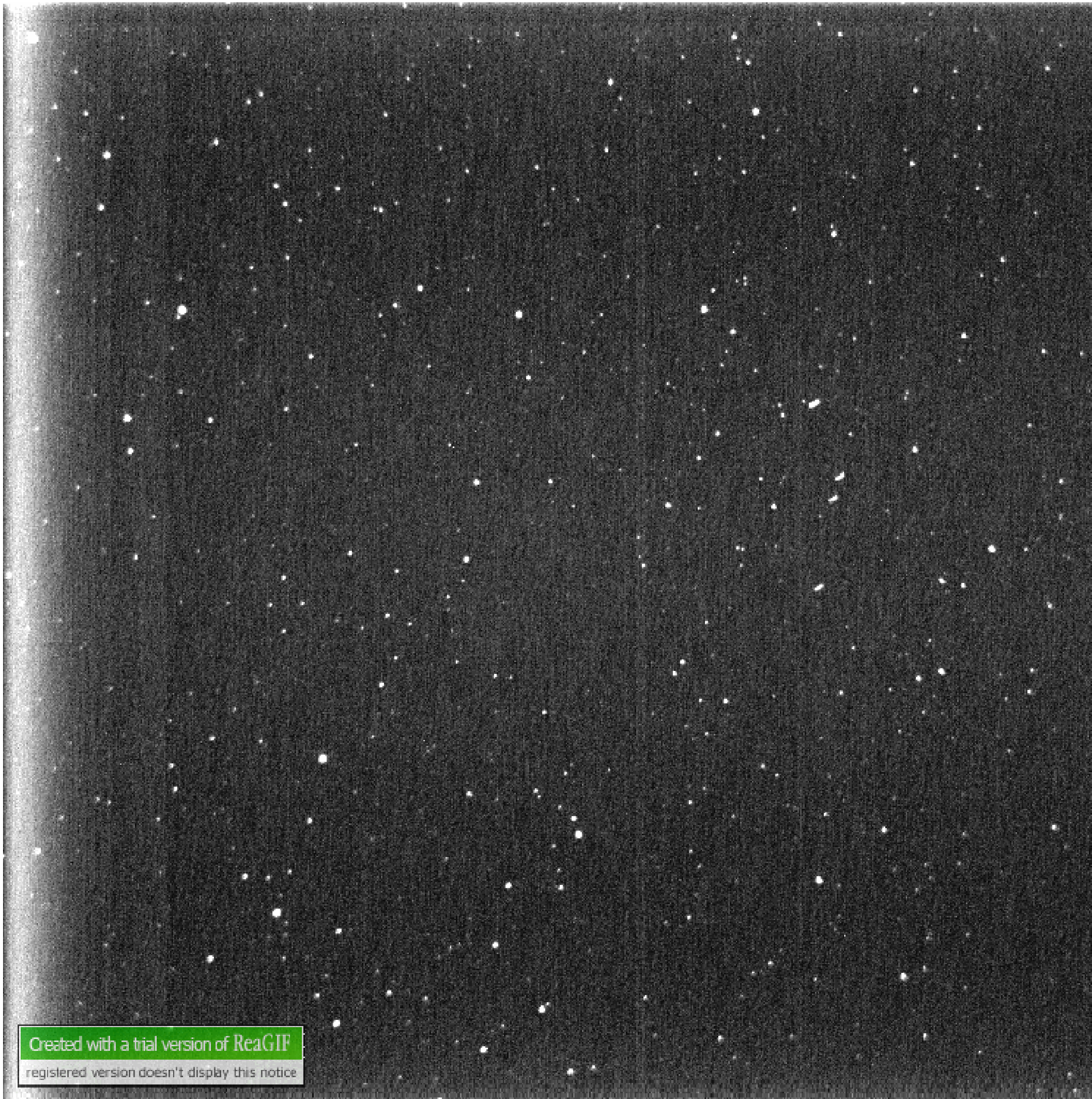
The exact time when the object will appear in the FOV is not necessary, since the drift-scan can be operated earlier than prediction.

(2) Faint objects can be detected by a small telescope

Exposure time of the faint object can be extended through charge-tracking.

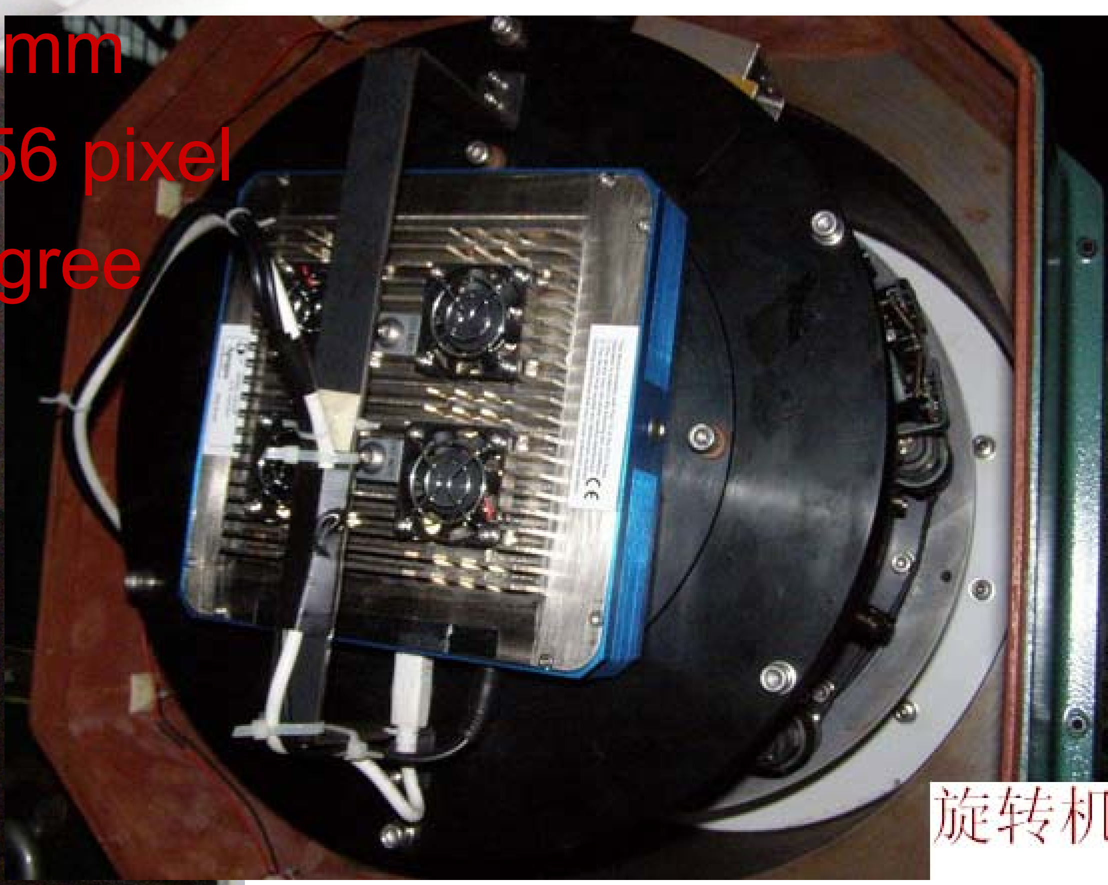
(3) Precise position and magnitude can be obtained

Both the images, of the object and of the reference stars, are PSF (circle) shaped.

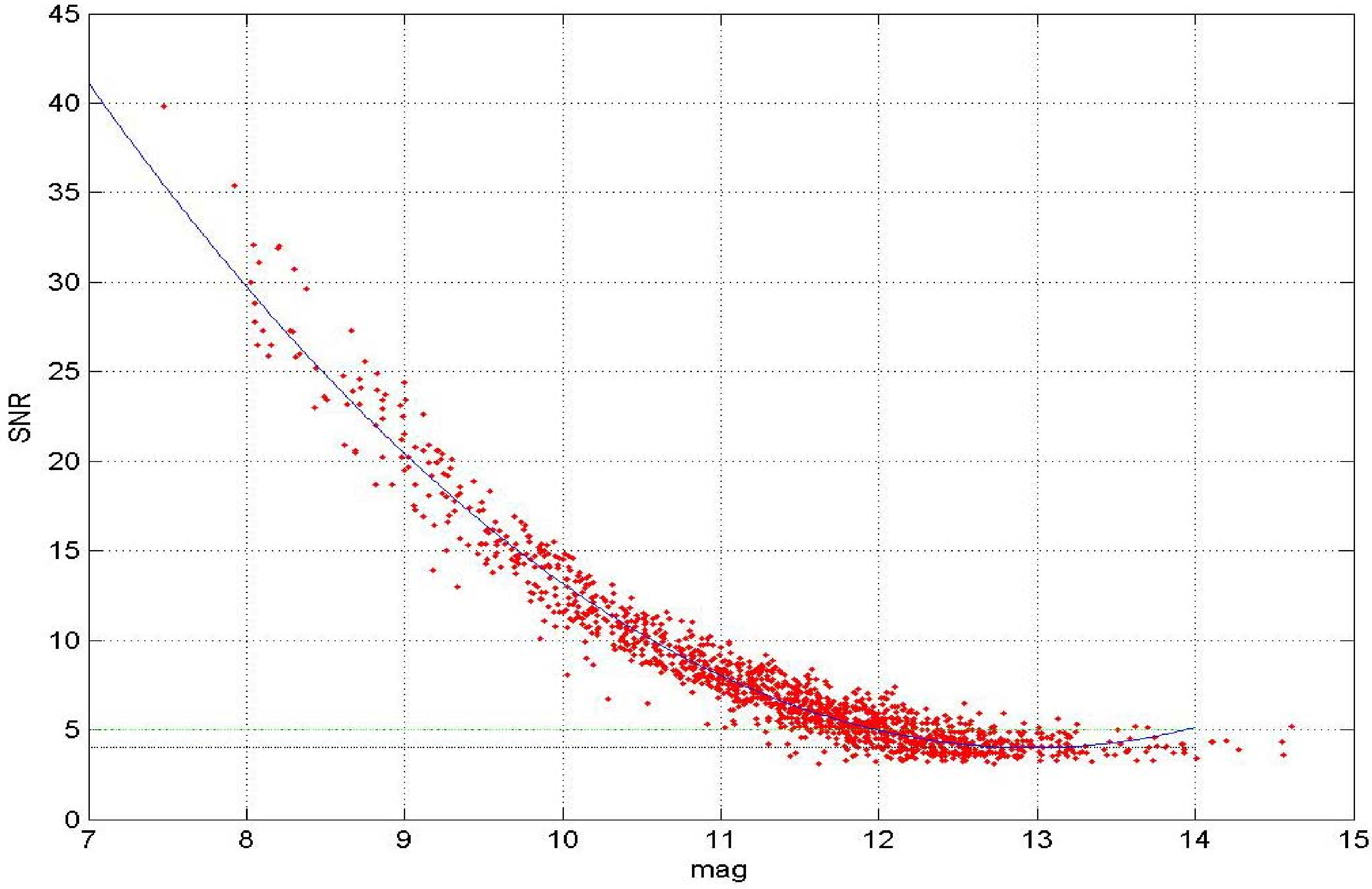


First Results – Shanghai - Large FOV

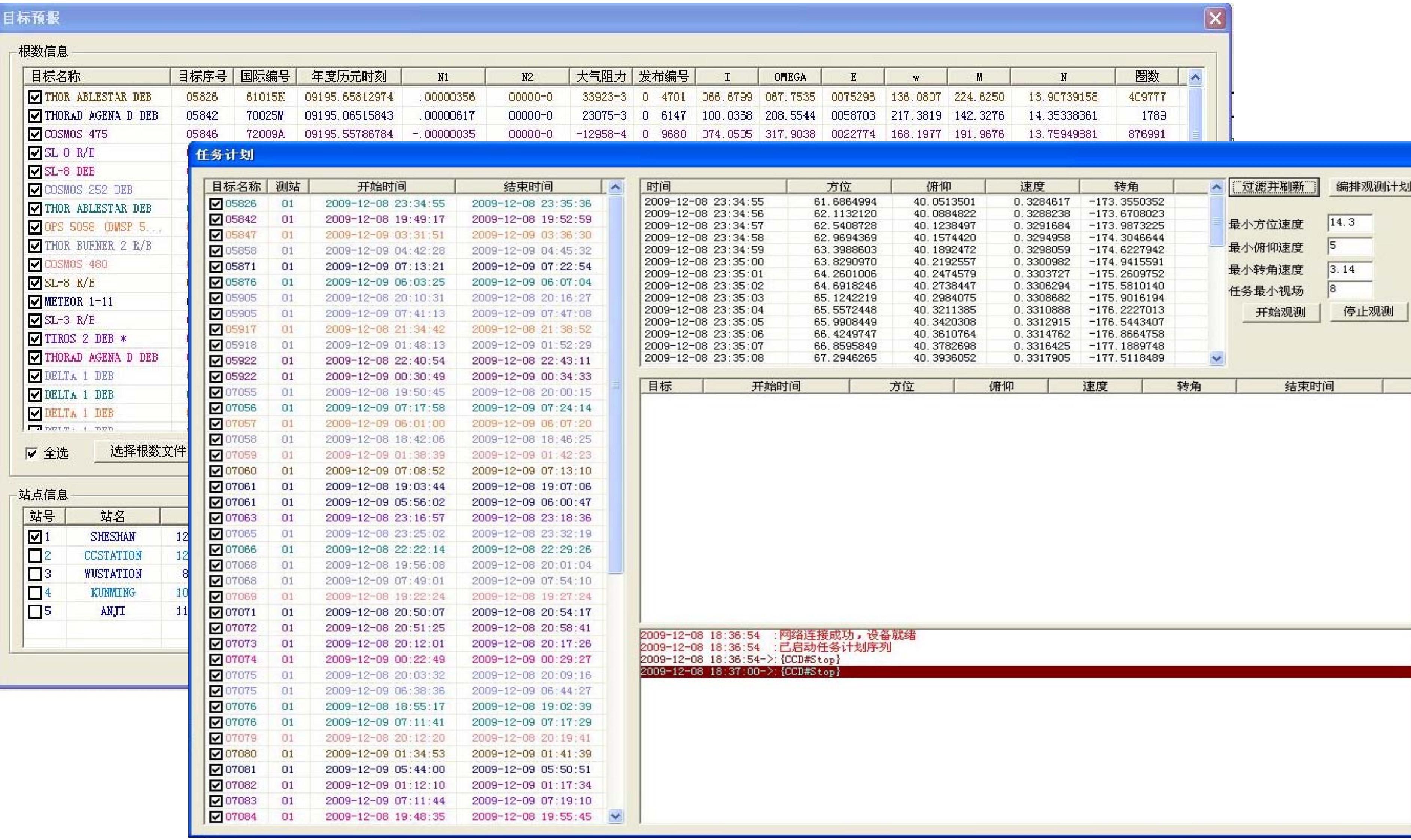
- Diameter: 300 mm
- Focal length: 250 mm
- CCD camera: Apogee U9000
- CCD pixel size: 0.012 mm
- CCD array: 3056 * 3056 pixel
- CCD Fov: 8.4 * 8.4 degree



Magnitude for 1sec exposure



Automatic observation control



laser-ranging satellite. (13~14mag)

Name/ Number	Diameter (cm)	Range (km)	Exposure Time (sec)	SNR
Lageos01 /08820	60	6200	15	10
Lageos02 /22195	60	6500	15	13
Stella /22824	24	1900	12	25

space debris (13~14magnitude)

Name/ Number	RCS (m*m)	Range (km)	Exposure Time (sec)	SNR
FENGYUN 1C DEB/29746	0.028	3785	15	5.2
Cosmos 1275 DEB/12730	0.15	1168	8	20

Precision estimation

Comparison with standard orbit of AJISAI satellite

Obs.date	Arc length (s□	Sigma (arcsec)
2011-03-07	520	6.1
2011-03-28	388	5.8
2011-03-30	553	6.9
2011-03-31	456	5.9

First Results – Valinhos – Astrometry on Smaller field

<u>MEADE</u> LX200 40mm f/10 **Schmidt-Cassegrain**

CCD: u9000 Apogee, 1528 ×1528

Pixel scale: 1.278 arcsec/px

FOV: 0.54 × 0.54 deg

mount: alt-azim

control: DaySky

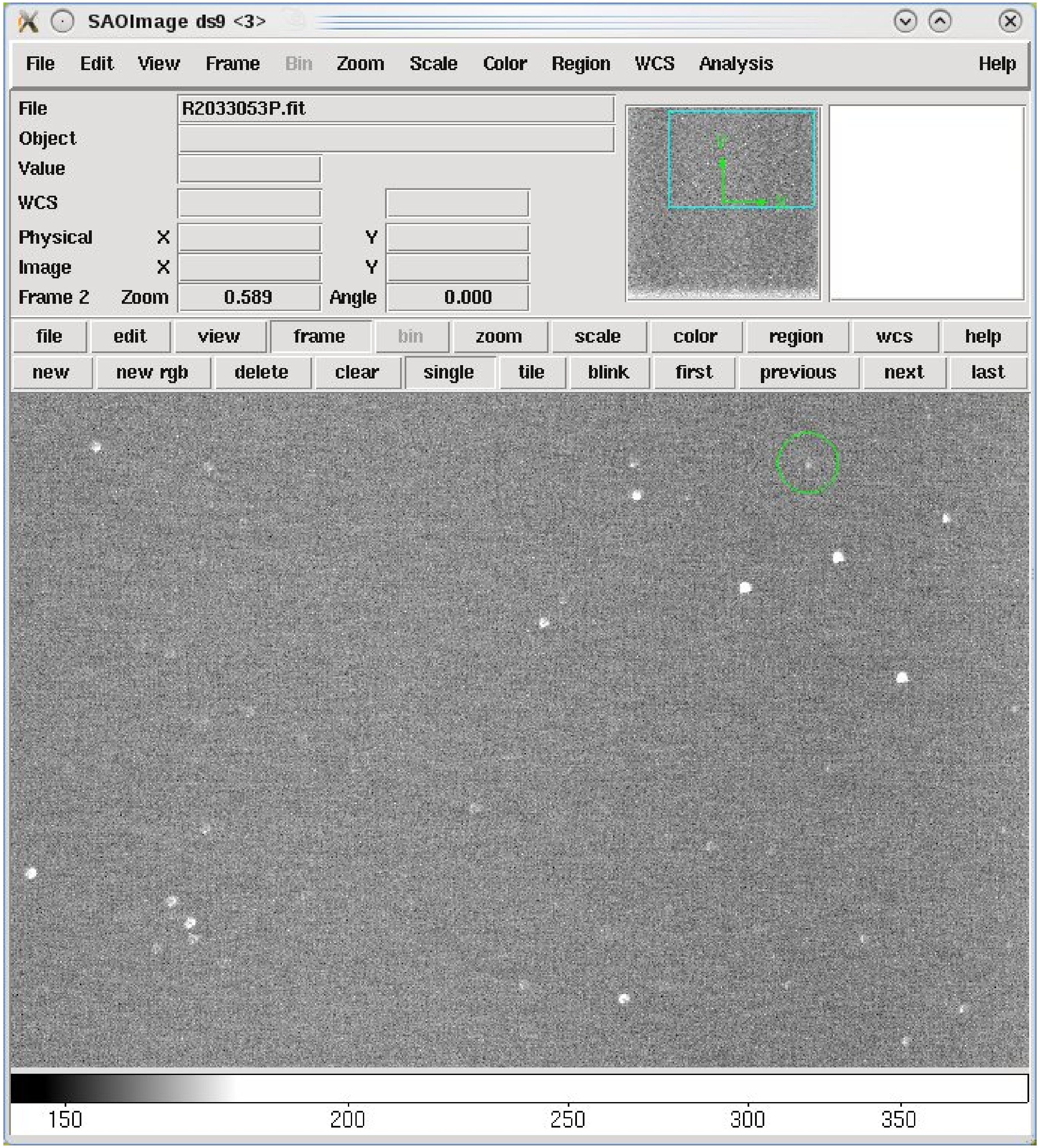
Aquisition: RDS

First Results – Valinhos – Astrometry on Smaller field

- 26 nights of trial observation

  between September/2011 and May/2012
- assisted observations from Observatorio Nacional

  at Rio de Janeiro
- 8 nights lost for clouds, link or equipment
- GEO satellites
- plus 5 operational Brazilian satellites
- and space debris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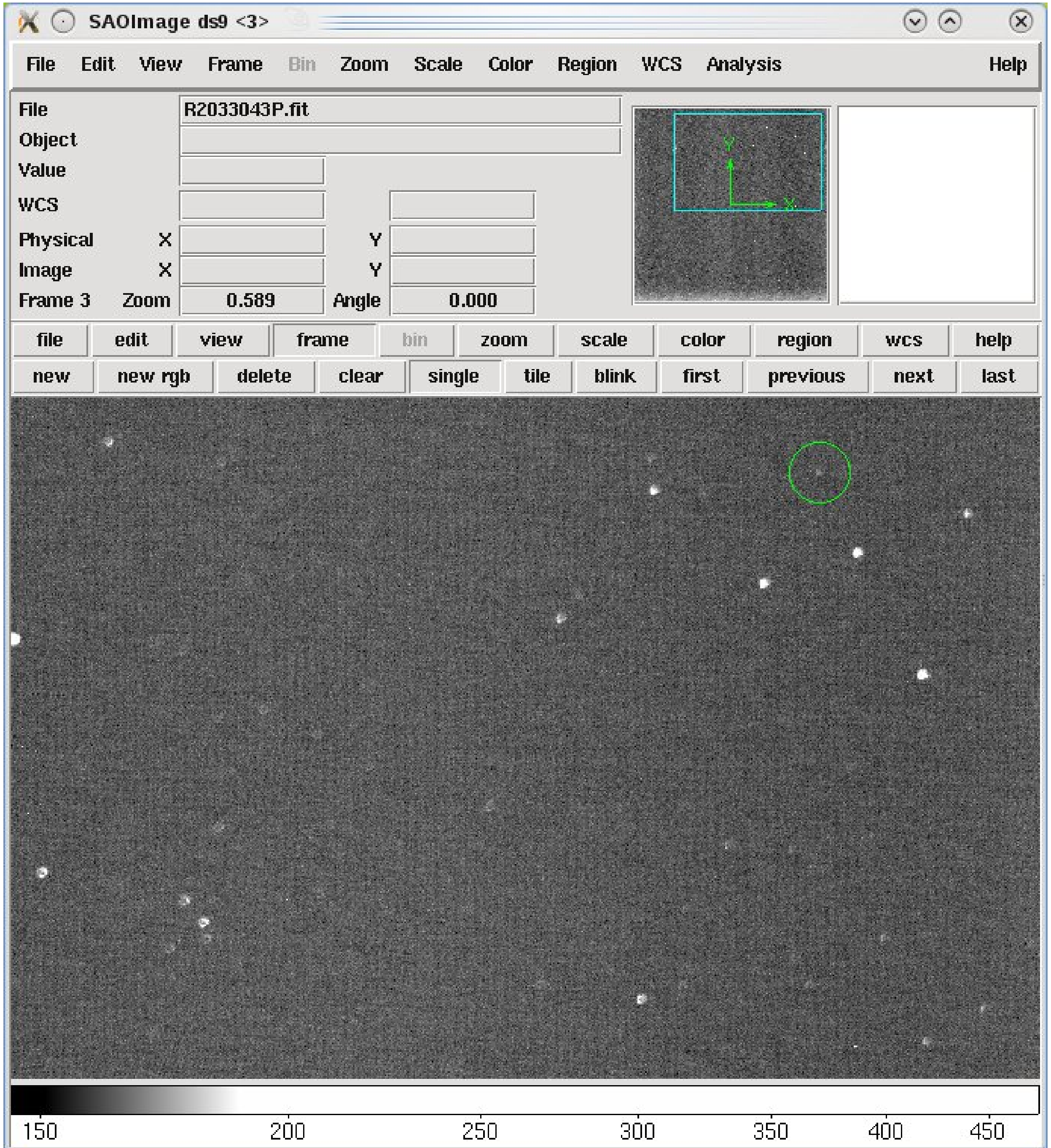
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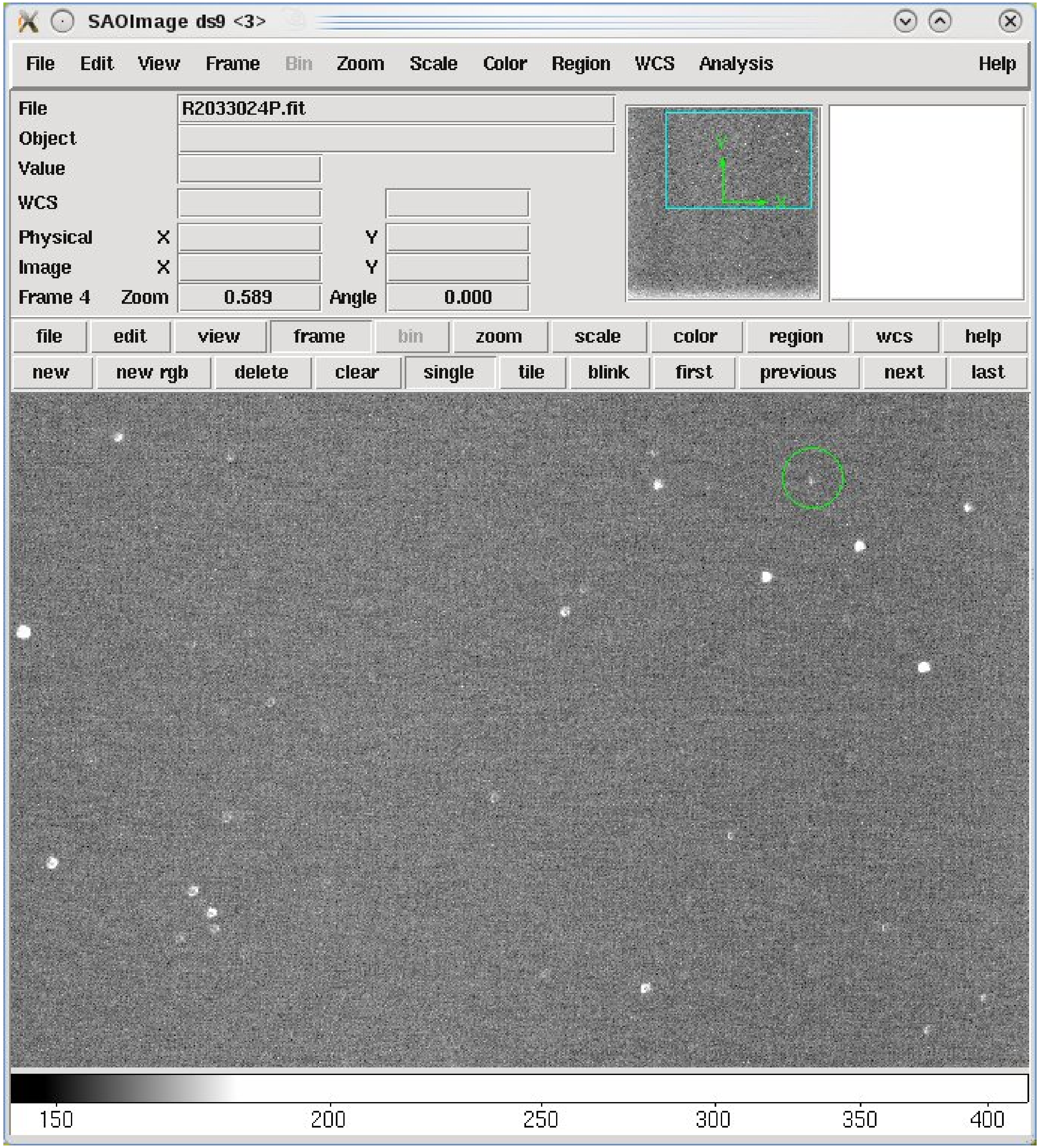
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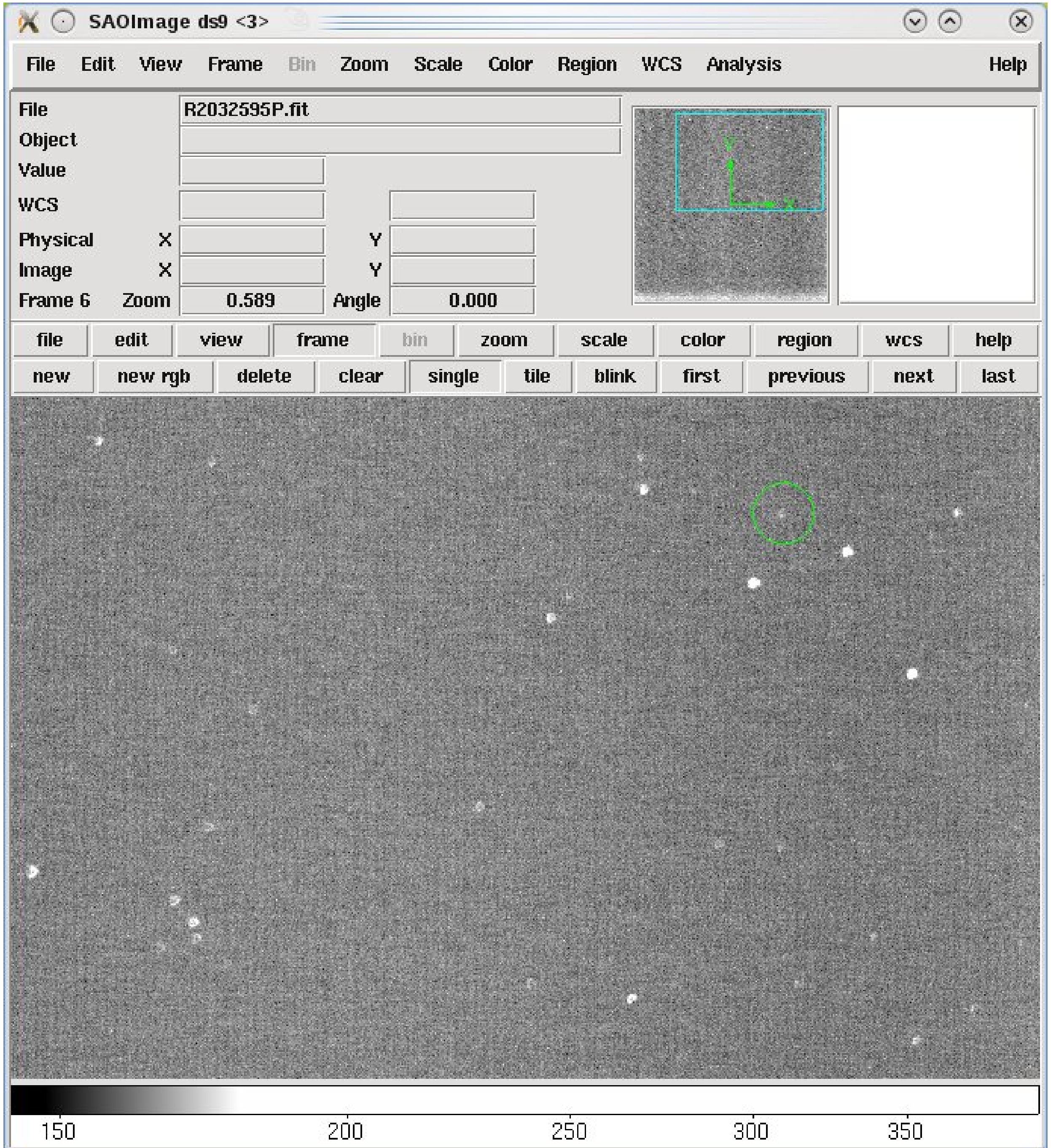
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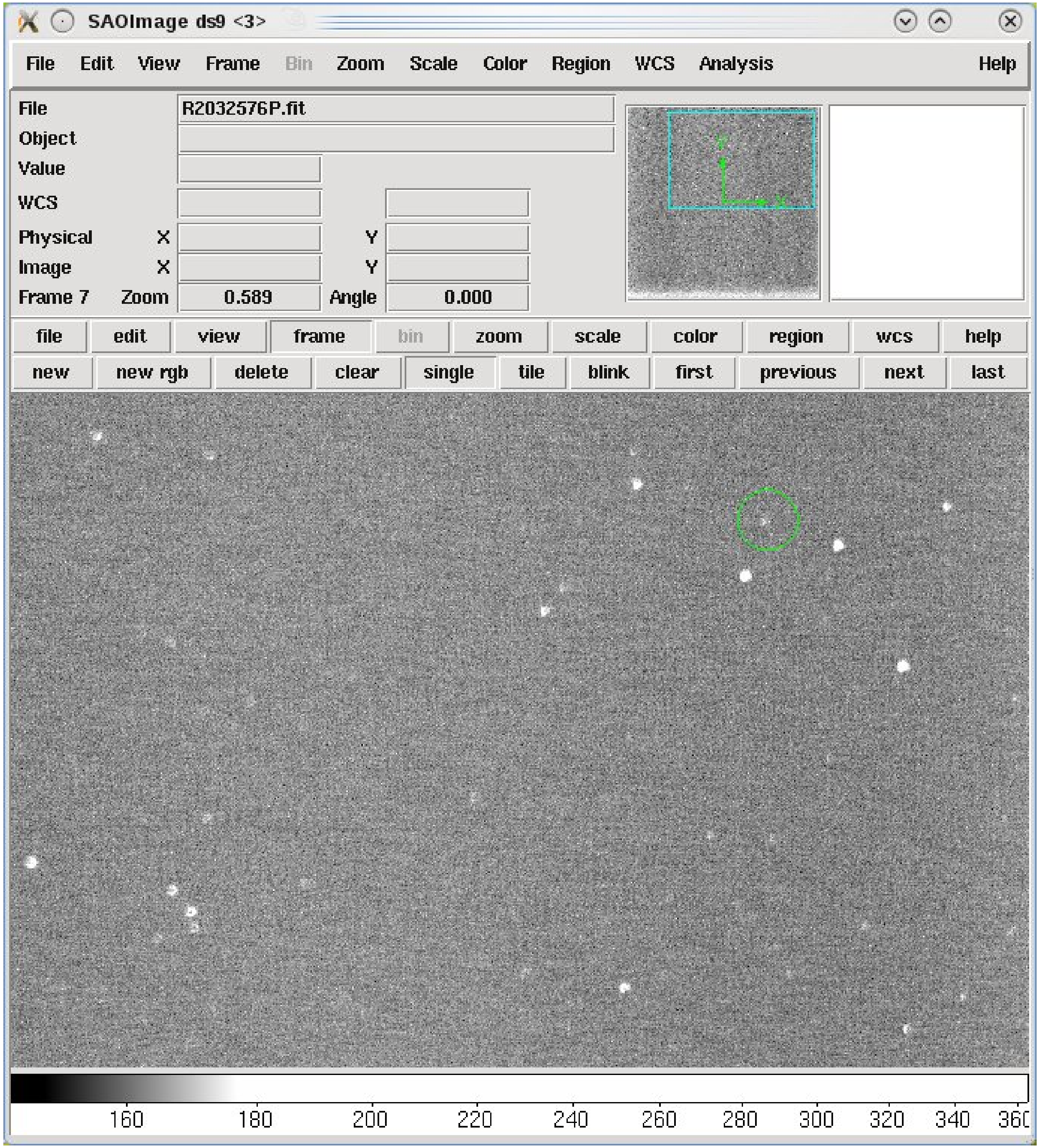
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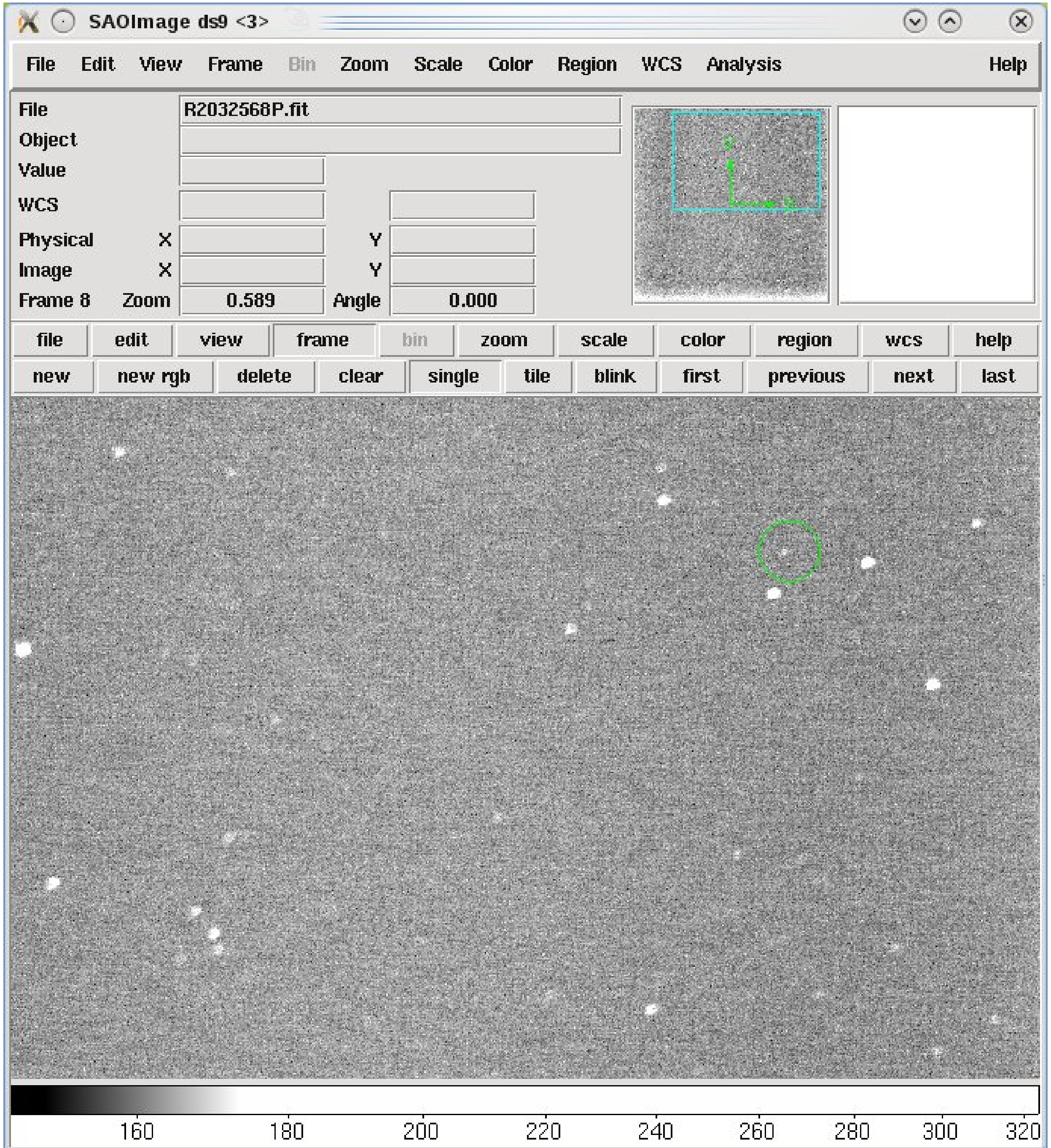
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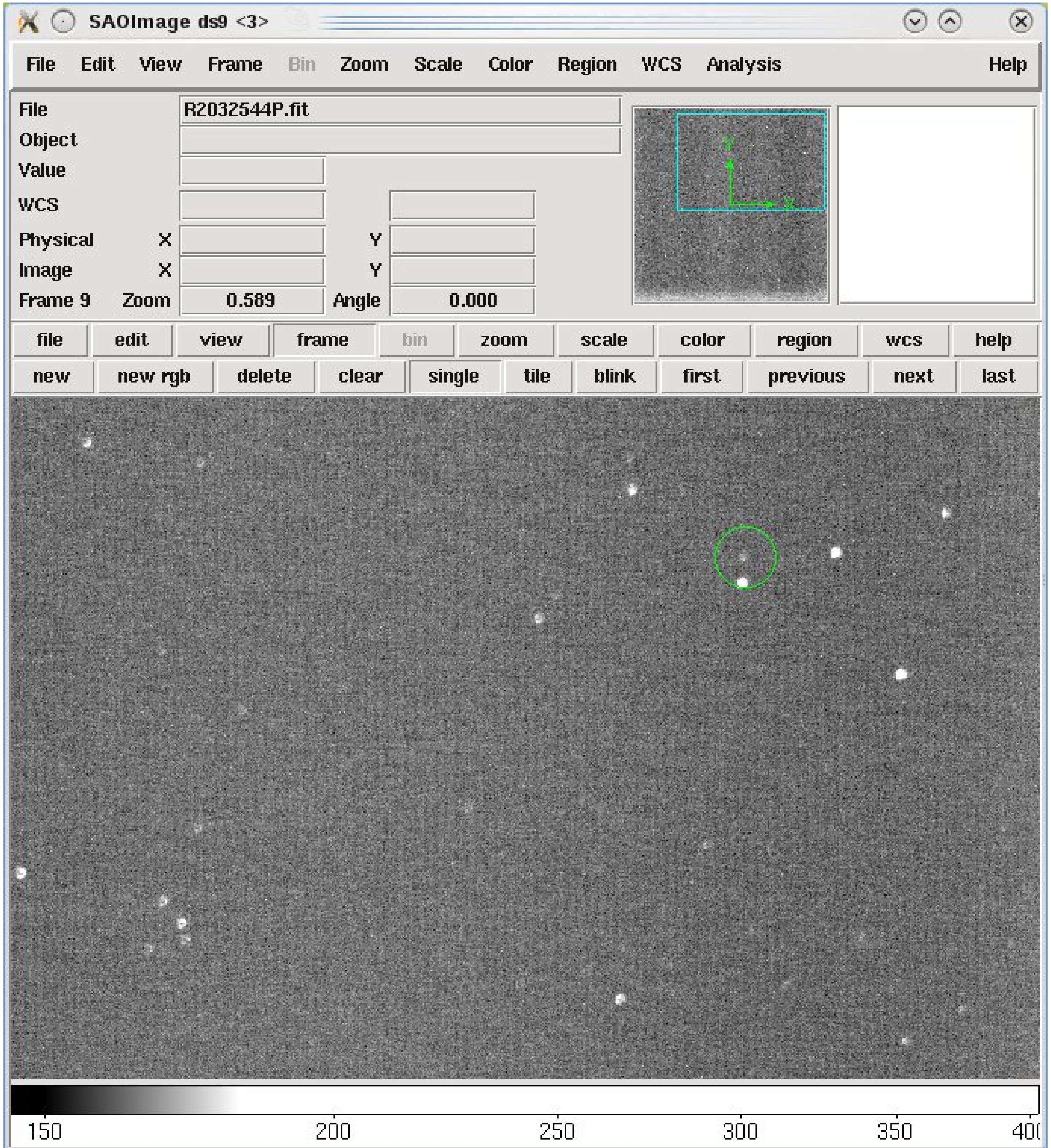
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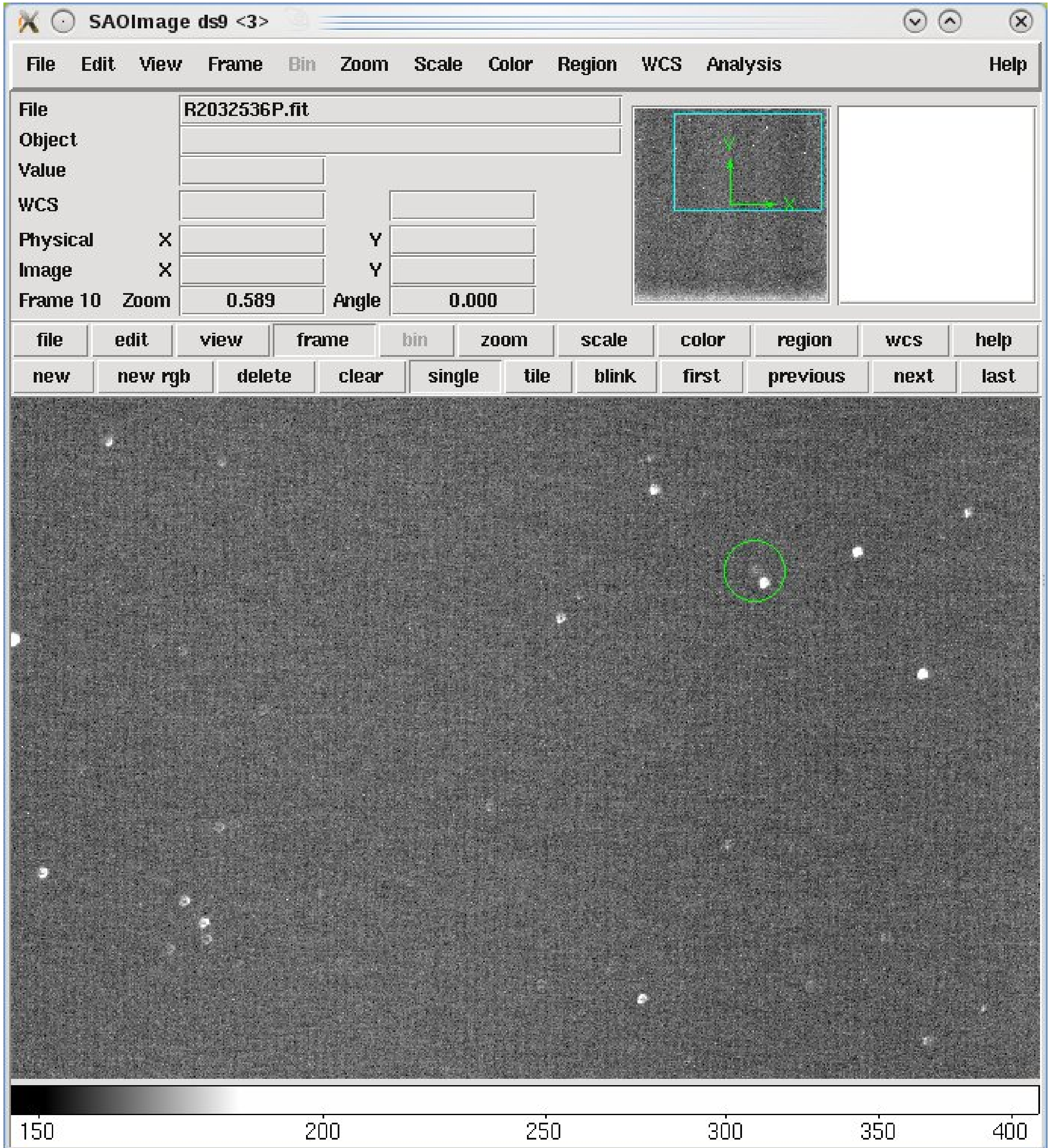
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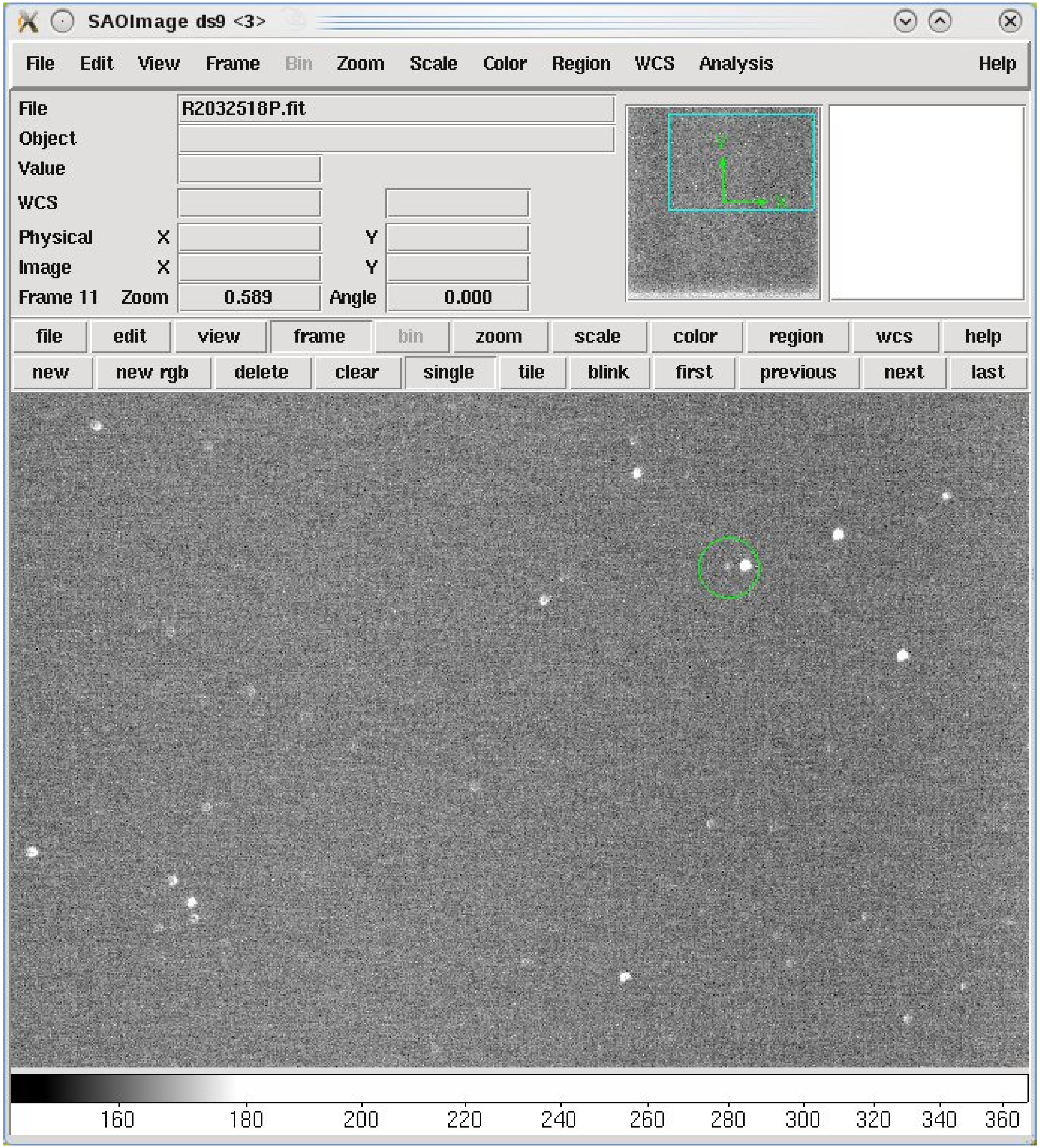
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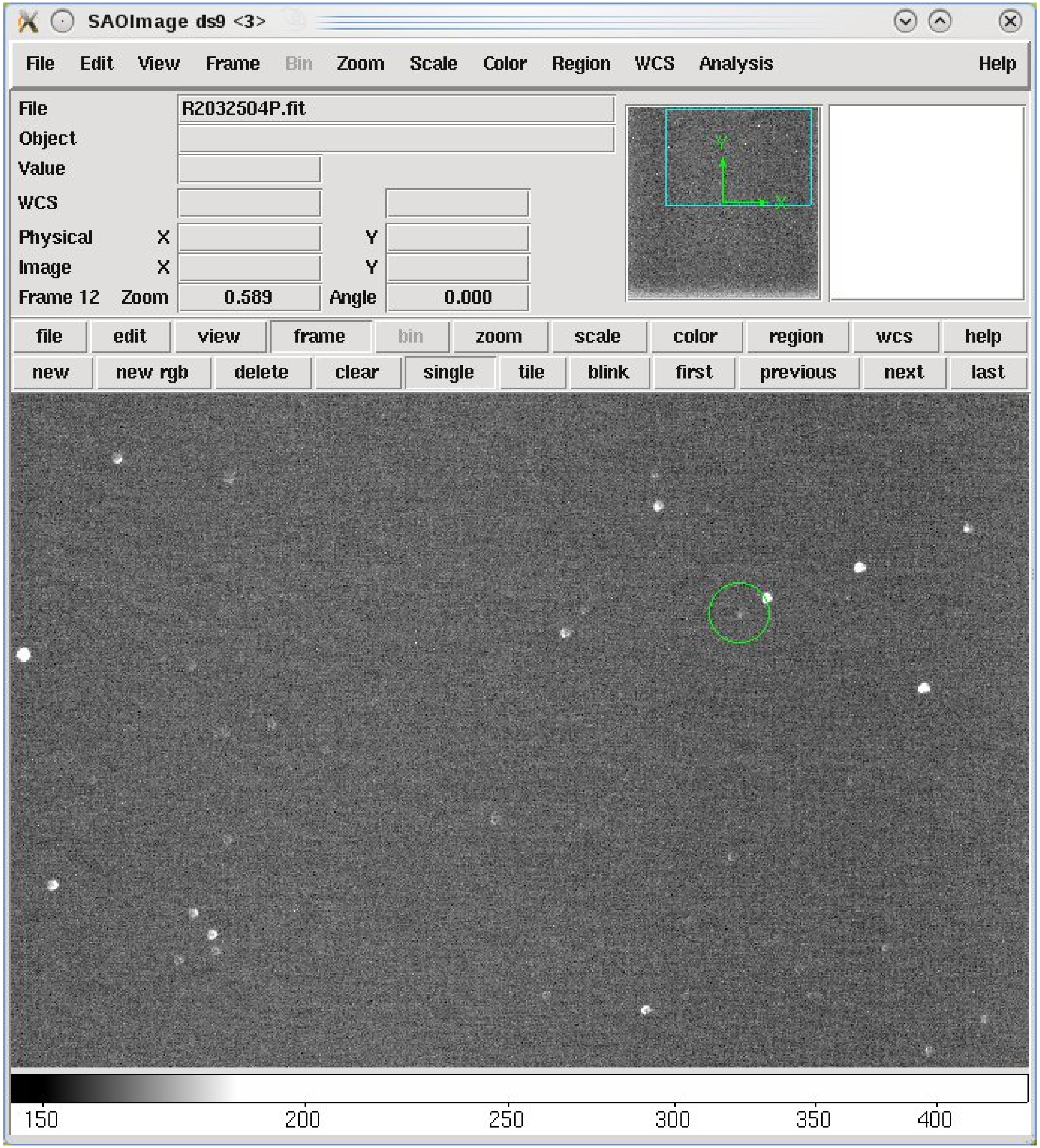
new new rgb delete clear single tile blink first previous next last
160 180 200 220 240 260 280 300 320 340 360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Object
Value
WCS
Physical X Y
Image X Y
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file edit view frame bin zoom scale color region wcs help
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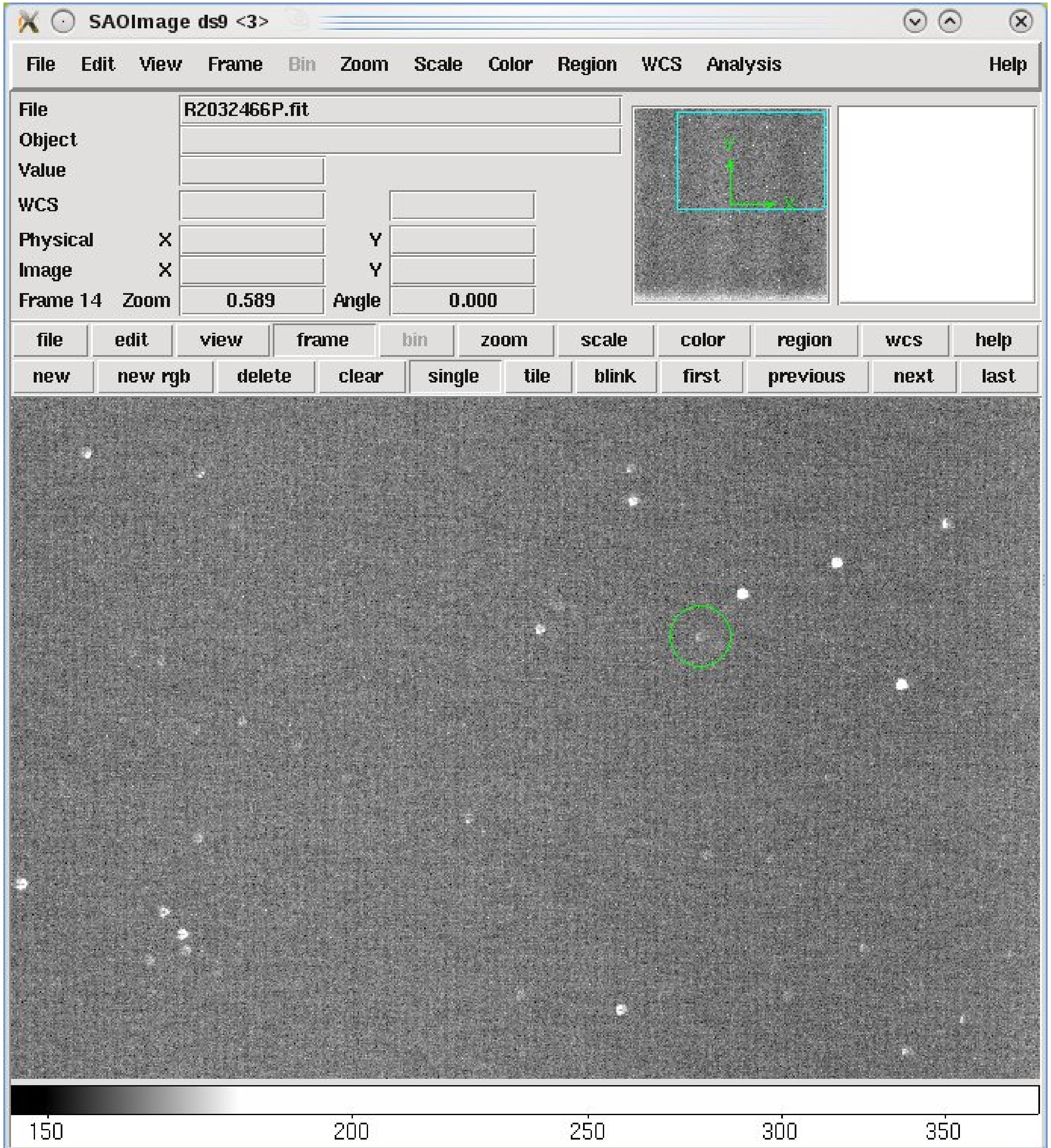
150 200 250 300 350 400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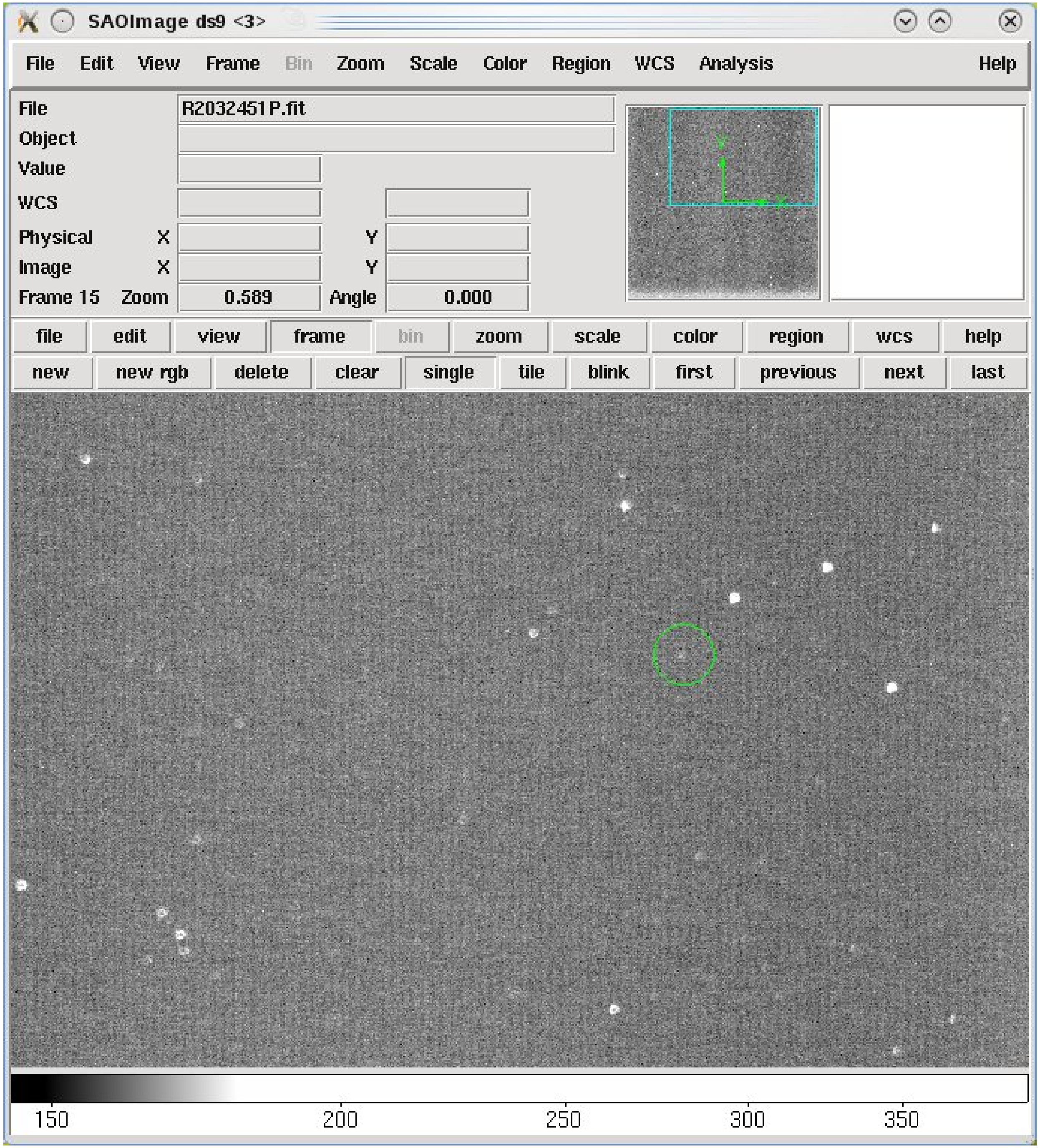
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Image X Y
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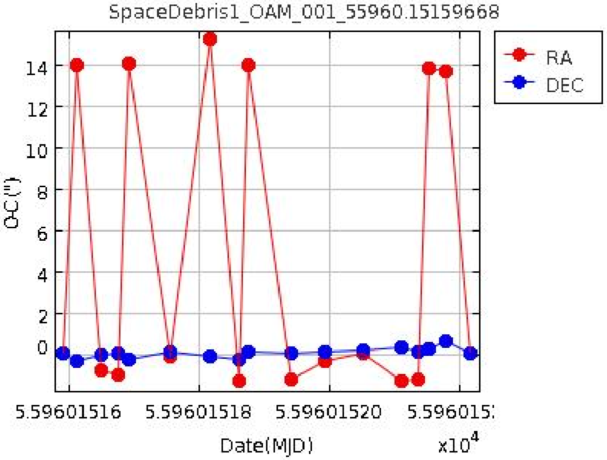
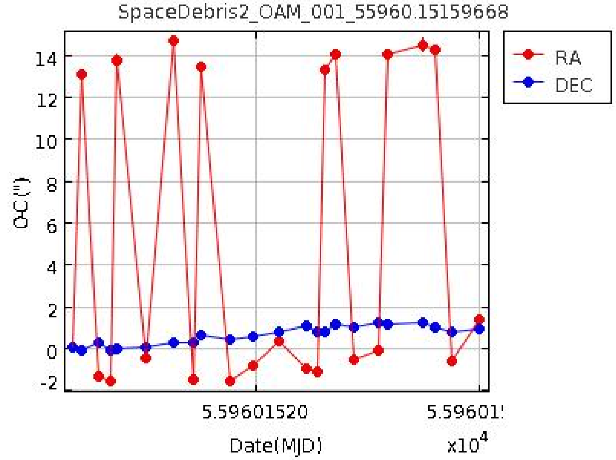
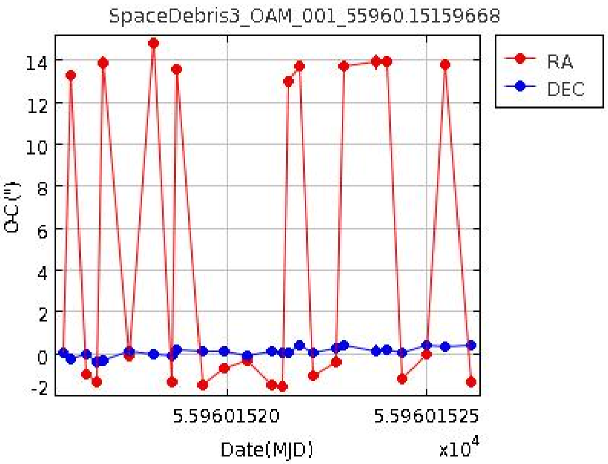
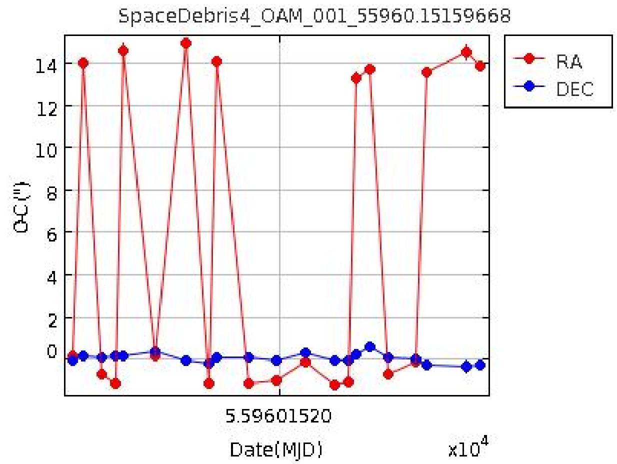
150 200 250 300 350

First Results – Valinhos – Astrometry on Smaller field

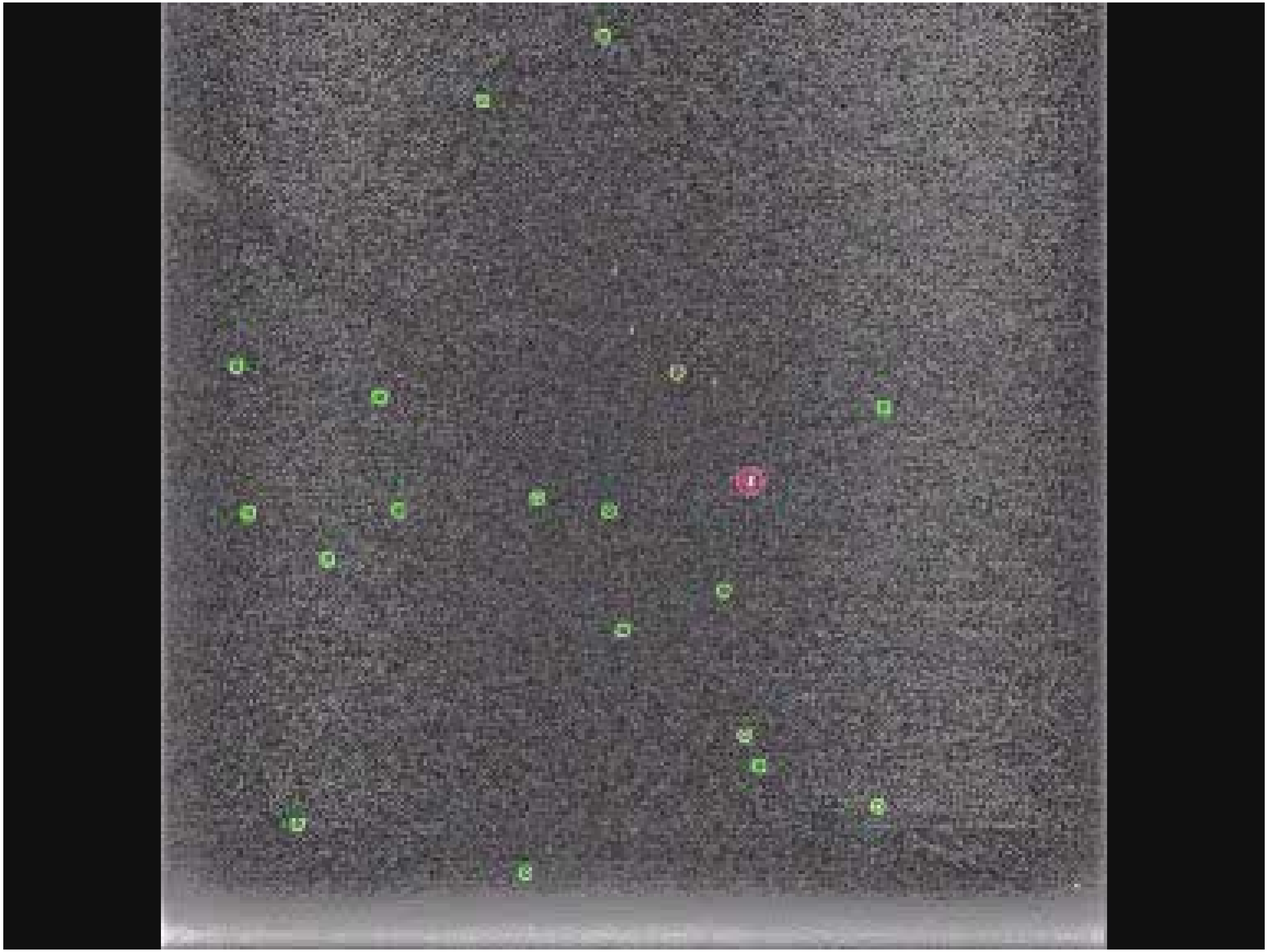








Target	<O-C>α	<O-C>δ	σ(O-C)α	σ(O-C) δ	Targer/Images	<S/N>
SpDeb1	4.526	0.014	7.323	0.242	17/ 34	52.9
SpDeb2	5.006	0.566	7.292	0.457	23/34	27.0
SpDeb3	4.894	0.018	7.341	0.216	25/34	26.1
SpDeb4	5.565	-0.040	7.502	0.230	21/34	22.4



Conclusions

1) Limited magnitude of different telescopes with different exposure time (equipped with a U9000)

D (mm)	F (mm)	FOV □deg□	L-mag (exp=60s)	L-mag (exp=10s)	L-mag (exp=5s)	L-mag (exp=1s)
250	500	4.0×4.0	16.0mag	14.1mag	13.4mag	11.6mag
400	600	3.5×3.5	17.0mag	15.1mag	14.4mag	12.6mag
600	900	2.3×2.3	17.8mag	15.7mag	14.9mag	13.2mag
1000	1500	1.4×1.4	19.0mag	17.1mag	16.3mag	14.6mag

Conclusions

2) Apparent magnitude of different size objects of different orbit

size(cm) / orbit(km)	2*2	5*5	7.5*7.5	10*10	20*20	30*30	50*50
200	14.4	12.4	11.5	10.9	9.4	8.6	7.4
300	15.3	13.3	12.4	11.8	10.3	9.4	8.3
400	15.9	13.9	13.0	12.5	11.0	10.1	9.1
500	16.4	14.4	13.5	12.9	11.4	10.6	9.4
600	16.8	14.8	13.9	13.3	11.8	10.9	9.8
800	17.5	15.5	14.6	14.0	12.5	11.6	10.5
1000	17.9	15.9	15.0	14.4	12.9	12.1	10.9
1200	18.3	16.3	15.4	14.8	13.3	12.5	11.3
1500	18.8	16.8	15.9	15.3	13.8	12.9	11.8

Conclusions

3) The time that different orbit objects pass the FOV of different telescopes (unit is second)

Orbit(km)	D=250mm	D=400mm	D=600mm	D=1000mm
200	1.8s	1.6s	1.0s	0.6s
300	2.3	2.4	1.6	1.0
400	3.7	3.2	2.1	1.3
500	4.6	4.0	2.6	1.6
600	5.6	4.9	3.2	1.9
800	7.6	6.6	4.3	2.6
1000	9.5	8.3	5.5	3.3
1200	11.4	10.0	6.6	4.0
1500	14.8	13.0	8.5	5.2

Conclusions

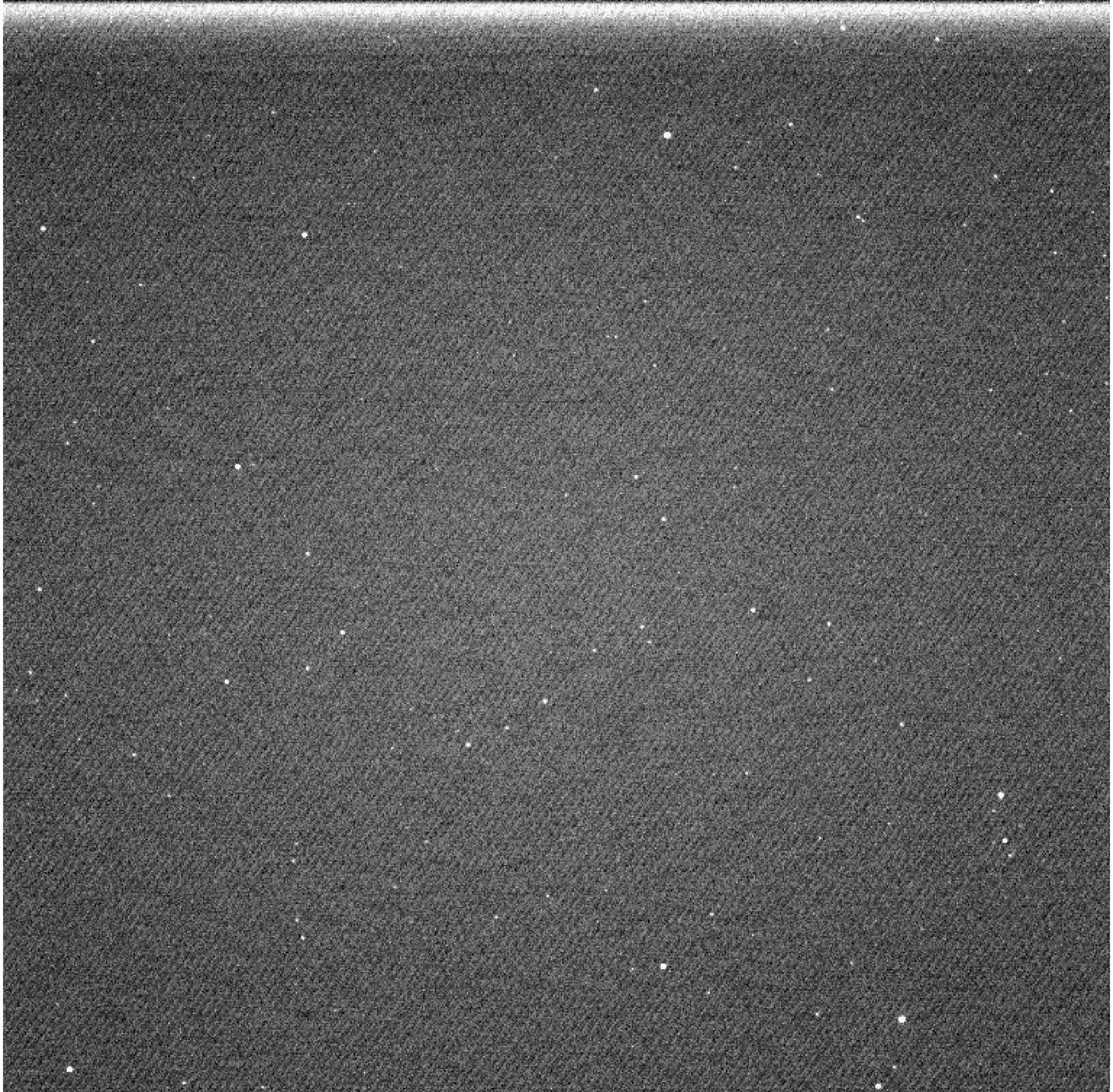
- A telescope of D=400mm, F=600mm, equipped with a U9000 CCD, can catch a space debris with size of ~2cm*2cm

- Sample systems (telescope+ rotating drift-scan CCD+software) are already regularly operating in China and in Brazil.

Sample observations

- **GPS   23204**
- **Orbit altitude: 19000km**
- **Orbit inclination: 98°**
- **Exposure time of satellite: 30**

- **GPS 23736**
- **Orbit altitude: 19000km**
- **Orbit inclination: 86°**
- **Exposure time of satellite: 30**



- **COSMOS 23045**
- **Orbit altitude: 19000km**
- **Orbit inclination: -90°**
- **Exposure time of satellite: 30**

- **LEO 24827**
- **Orbit altitude: 1429km**
- **Orbit inclination: 104°**
- **Exposure time of satellite: 2**

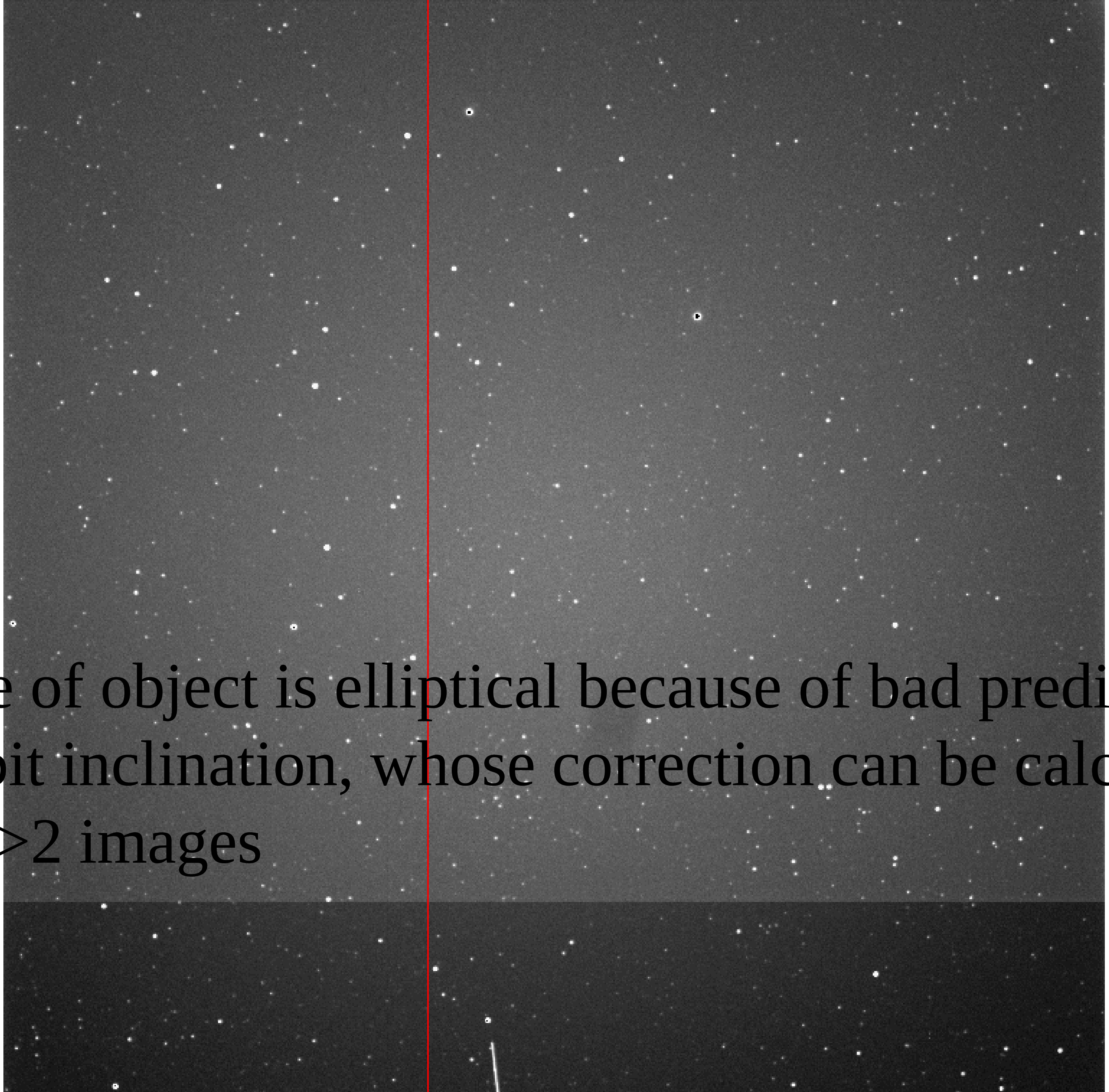


Image of object is elliptical because of bad prediction of orbit inclination, whose correction can be calculated from >2 images

- **LEO 14521**
- **Orbit altitude: 1526km**
- **Orbit inclination: 109°**
- **Exposure time of satellite: 2**